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DEVELOPMENT OF A PAVEMENT MAINTENANCE MANAGEMENT SYSTEM
VOLUME VI: M&R GUIDELINES -- VALIDATION AND FIELD APPLICATIONS

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This report presents maintenance and repair (M&R) guidelines and economic analysis procedures for determining optimum repair strategies for a given airfield pavement. The procedures consist of data collection, condition evaluation, identification of feasible M&R alternatives, performing economic analysis, and selection of the optimum M&R alternative.

The primary data to be collected are pavement distress types, severities, and amount. This information is then used to compute a pavement condition

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index (PCI), which is based on a scale of 0 to 100 and measures the pavement structural integrity and surface operational condition. Pavement evaluation is performed through a stepwise procedure which is largely dependent on the PCI and distress data, since they have been found to correlate highly with M&R needs. Other direct measurements, such as profile roughness, hydroplaning potential, and load-carrying capacity, are also included in the evaluation procedure. Guidelines for rational determination of feasible M&R alternatives are presented, based on the results from the pavement evaluation. Included in the guidelines are acceptable alternatives for the localized repair of different distress types at different severity levels. Economic analysis is performed among feasible M&R alternatives, using the present worth method. The optimum alternative is selected based on the results of the economic analysis, mission, and policy.

The procedures have been tested and validated through several field applications. Two of these applications -- one for an asphalt concrete (AC) surfaced runway and one for a concrete apron -- are presented in this report.

PREFACE

This report documents work accomplished by the U.S. Army Construction Engineering Research Laboratory (CERL), P.O. Box 4005, Champaign, IL 61820, under Project DTC-8-128 from the Air Force Engineering and Services Center (AFESC), Tyndall AFB, FL. Mr. Mike Womack was Project Engineer for AFESC.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). It will be available at NTIS to the general public, including foreign nations.

The assistance of the following Air Force Engineers is gratefully acknowledged; Messrs Don Brown and Mike Womack (AFESC), Mr. Carl Borgwald (HQ AFLC), Mr. Charles York (HQ MAC), Mr. William Peacock (HQ TAC), Mr. Martin Noland (HQ AFSC), Messrs Charles Mckeral and Roy Almendared (HQ ATC), Mr. Larry Olson (HQ ANG), Mr. Harry R. Marien (HQ USAFE), Mr. Leo Frelin (HQ AAC), Mr. Richard Williams (Myrtle Beach AFB), and Mr. Jerry Rankin (Eglin AFB). Acknowledgement is due to Dr. Michael I. Darter for his participation in the development of the maintenance and repair guidelines as presented in Volume III of this report. Appreciation is also due to Mr. Awad Kabashi of CERL for his assistance in the preparation of this report.

This technical report has been reviewed and is approved for publication.

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TABLE OF CONTENTS

CONTENTS (CONCLUDED)

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (CONCLUDED)

LIST OF FIGURES (CONCLUDED)

LIST OF TABLES

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SECTION I

INTRODUCTION

BACKGROUND

The Air Force has a very large inventory of pavements, most of which are fast approaching the end of their economic design life. Therefore, it is becoming increasingly important to develop a means of rationally determining maintenance and repair (M&R) needs and alternatives based on a comprehensive pavement evaluation. This requirement is being addressed as part of a pavement maintenance management system being developed by the Air Force Engineering and Services Center (AFESC). The system has been under development by the U.S. Army Construction Engineering Research Laboratory (CERL) since 1975. This research has developed the Pavement Condition Index (PCI) for measuring the condition rating of jointed concrete and asphalt- or tar-surfaced airfield pavements. The determination of PCI, a score from 0 to 100 that measures pavement structural integrity and surface operational condition, is based on type, severity, and amount of measured distress (Reference 1). The PCI agrees closely with the collective judgment of experienced pavement engineers and relates strongly to M&R needs. It is being implemented by the Air Force worldwide.

During FY77, the Air Force developed preliminary guidelines for determining M&R needs and alternatives. These guidelines are largely dependent on PCI and distress data because they correlate closely with M&R needs. Other measurements included in the guidelines are profile roughness, hydroplaning potential, and load-carrying capacity. The Air Force has also developed an economic analysis procedure for performing a present-worth analysis of feasible M&R alternatives for any specific pavement. The procedure considers initial cost, annual maintenance cost, and the salvage value at the end of the selected analysis period. The preliminary M&R guidelines and economic analysis procedure were documented in Volume III of this report (Reference 2).

OBJECTIVE

The objective of this work was to field test, validate, and revise (as necessary) the preliminary M&R guidelines and economic analysis procedure developed in FY77. The improved procedure will be used to select the optimum M&R alternatives for airfield pavements.

APPROACH

The M&R guidelines and economic analysis procedure were tested in several field applications. Many pavement features at various Air Force bases were surveyed, feasible M&R alternatives were identified, and an economic analysis was performed to select the best alternative. Application of the procedures was coordinated with the appropriate command and base engineers. The procedures and representative results obtained from field applications were further discussed during a workshop attended by many Air Force command and base engineers.

ORGANIZATION OF REPORT

Section II briefly describes the development and use of the PCI procedure used to determine the condition rating of a pavement feature. The improved and validated M&R guidelines and economic analysis procedure are presented in Sections III, IV, and V. Section VI describes the field application of the procedures used to evaluate the asphalt runway at Pope Air Force base. Section VII describes the field application of the procedures used to evaluate a concrete apron at Barksdale Air Force base. Section VIII provides conclusions and recommendations.

SECTION II

PAVEMENT CONDITION INDEX

DESCRIPTION

The PCI is a numerical indicator of pavement condition that is directly related to the pavement's structural integrity (ability to resist fracture, distortion, and disintegration) and its surface operational condition. The PCI is a function of (1) type of distress; (2) severity of distress, such as width and degree of crack spalling or rut depth; and (3) density of distress, which is the amount of distress divided by area surveyed expressed in percent. The development of a meaningful condition index would not have been possible if any of these three distress characteristics had been ignored. The PCI is expressed mathematically as follows.

$$PCI = C - \left[\sum_{i=1}^{P} \sum_{j=}^{m_i} a(T_i, S_j, D_{ij})\right] F(t,q) \qquad \text{[Equation 1]}$$

where PCI = pavement condition index

C = a constant depending on desired maximum scale value

a( ) = deduct weighting value depending on distress type T_i, level of severity S_j, and density of distress D_{ij}

i = counter for distress types

j = counter for severity levels

p = total number of distress types for pavement type under consideration

m_i = number of severity levels on the i^{th} type of distress

F(t,q) = an adjustment function for multiple distresses that varies with total summed deduct value (t) and number of deducts (q).

The development of the PCI consisted of defining distress types and severity levels (Reference 3), and developing individual distress deduct curves and an adjustment function for multiple distress correction (Reference 4). The PCI was verified by the assistance of many experienced Air Force engineers and field visits to many Air Force bases located in different climates and subjected to different traffic. During each field visit, many pavement sections were surveyed and the PCI was calculated according to the procedure guidelines (References 3 and 4). In addition, each pavement section was subjectively rated by at least four experienced engineers according to the scale shown in Figure 1 (Step 8); the pavement condition rating ($\overline{PCR}$) was determined by averaging the individual ratings of the

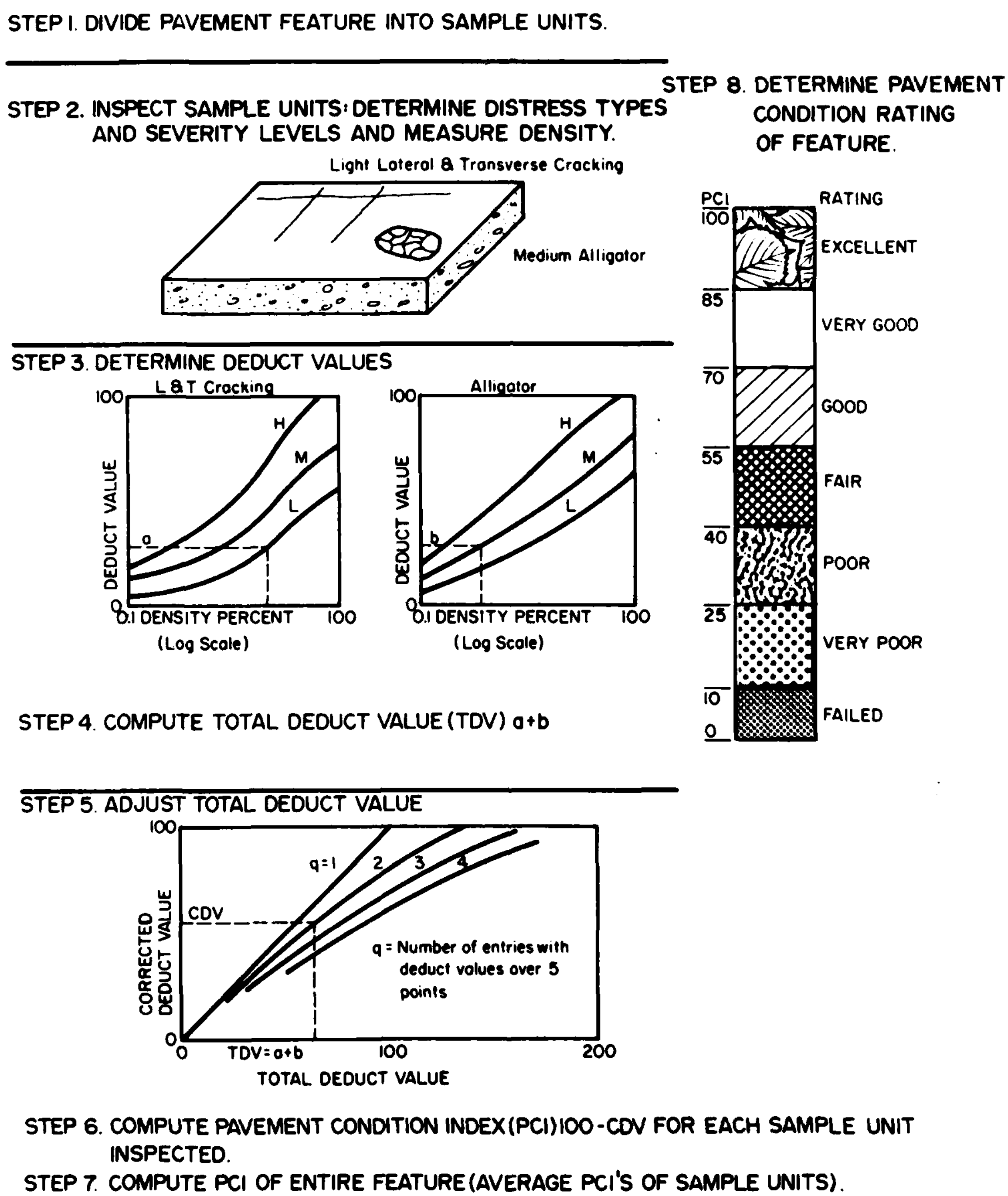

Figure 1. Steps for Determining PCI of a Pavement Feature.

engineers. When the development and field verification process was completed, excellent agreement was shown between the PCI and PCR. Figure 2 compares the PCI and PCR for asphalt-surfaced airfield pavements.

DETERMINATION OF THE PCI FOR A PAVEMENT FEATURE

A pavement feature is defined as a portion of pavement which (1) has consistent structural thickness and materials, (2) was constructed at one time, and (3) is subjected to the same type and approximately the same number of traffic repetitions.

The PCI of a given pavement feature can be determined by using the following steps (Figure 1):

1. The pavement feature is first divided into sample units. A sample unit for concrete pavement is approximately 20 slabs; a sample unit for asphalt is an area of approximately 5000 square feet.

2. The sample units are inspected and distress types and their severity levels and densities are recorded. It is imperative that criteria developed by Shahin, et al. (Reference 1) be used to identify and record the distress types.

3. For each distress type, density, and severity level within a sample unit, a deduct value is determined from an appropriate curve (Reference 1). Step 3 of Figure 1 provides an example of such a curve.

4. The total deduct value (TDV) is determined by adding all deduct values for each distress condition observed for each sample unit inspected.

5. A corrected deduct value (CDV) is determined from the appropriate curve (Reference 1); the CDV is based on the TDV and the number of distress conditions observed with individual deduct values over five points (see Step 5 of Figure 1).

6. The PCI for each sample unit is calculated as follows:

$$PCI = 100 - CDV \qquad \text{[Equation 2]}$$

7. The PCI of the entire feature is computed by averaging the PCIs from all the sample units inspected.

The feature's overall condition rating is determined from Figure 1, Step 8, which provides a verbal description of the pavement's condition as a function of its PCI value.

A procedure for inspection by sampling, which is based on a statistical model, has expedited inspection without loss of accuracy, and has been widely accepted and used by the Air Force engineers. A computer program has also been developed to expedite the PCI calculations (Reference 1).

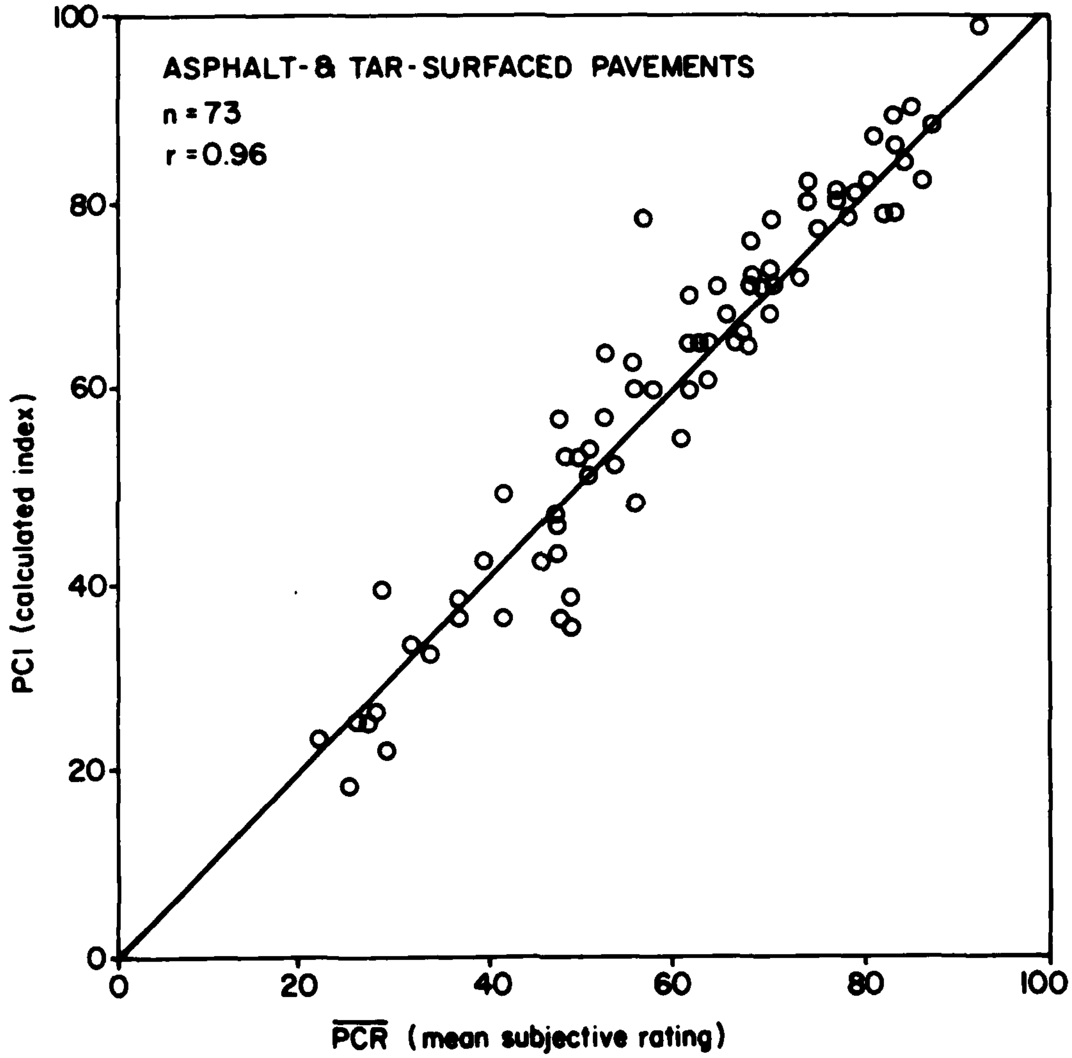

Figure 2. Correlation Between $\overline{PCR}$ and PCI for All Asphalt- or Tar-Surfaced Pavement Sections Surveyed (From M. Y. Shahin, M. I. Darter, and S. D. Kohn, Development of a Pavement Maintenance Management System, Volume I, Airfield Pavement Condition Rating, AFCEC-TR-76-27, Air Force Civil Engineering Center (AFCEC), November 1976).

SECTION III

PAVEMENT FEATURE EVALUATION FOR SELECTION OF M&R ALTERNATIVES

This section presents steps for evaluating the condition of a pavement feature. Major emphasis is placed on using the PCI and distress data to determine condition because they have been found to correlate highly with M&R needs. Also presented are instructions for using other direct measurements to supplement and verify evaluations in critical situations.

PAVEMENT EVALUATION STEPS

Figure 3 summarizes the pavement condition evaluation steps; the following is a brief description of each step:

Overall Condition

The mean PCI of a pavement feature represents the pavement's overall condition. This condition rating represents the consensus of a group of experienced pavement engineers and correlates highly with maintenance and rehabilitation needs (see Section IV).

The mean PCI of a feature is determined by computing the average of all sample units inspected within that feature (adjusted if additional nonrandom units are included) (Reference 1).

Variation of PCI Within Features

Variations of materials, construction, subgrade, and/or traffic loadings may cause certain portions of a given pavement feature to show a significantly different condition than the average of the overall feature. Areas having a poorer condition are of major concern. Variation within a feature occurs on both a localized, random basis (i.e., from material and variability), and a systematic basis (i.e., from traffic patterns).

Figure 4 has been developed from field data to provide guidelines for determining whether localized random variation exists. For example, if the mean PCI of the feature is 59, any sample unit having a PCI of less than 42 should be identified as a localized bad area. This variation or localized bad area should be considered when determining M&R needs.

Systematic variation occurs whenever a large concentrated area of the feature has a significantly different condition from the rest. For example, if traffic is channelized into a certain portion of a wide runway or a large apron, that portion may show much more distress (or poorer condition) than the rest of the area. Whenever a significant amount of systematic variability exists within a feature, the engineer should strongly consider dividing it into two or more features.

Facility: ______________________ Feature: ____________________

1. Overall Condition Rating - PCI

Excellent, Very Good, Good, Fair, Poor, Very Poor, Failed.

2. Variation ‹r Condition Within Feature - PCI

a. Localized Random Variation	Yes, No
b. Systematic Variation:	Yes, No

3. Rate of Deterioration of Condition - PCI

a. Long-term period (since construction)	Low, Normal, High
b. Short-term period (1 year)	Low, Normal, High

4. Distress Evaluation

a. Cause

Load Associated Distress	_____ percent deduct values
Climate/Durability Associated	_____ percent deduct values
Other (___) Associated Distress	_____ percent deduct values

b. Moisture (Drainage) Effect on Distress	Minor, Moderate, Major
5. Load-Carrying Capacity Deficiency	No, Yes
6. Surface Roughness	Minor, Moderate, Major
7. Skid Resistance/Hydroplaning (runways only)	No hydroplaning problems are expected
a. Mu-Meter	Transitional Potential for hydroplaning Very high probability
b. Stopping Distance Ratio	No hydroplaning anticipated Potential not well defined Potential for hydroplaning Very high hydroplaning potential
c. Transverse Slope	Poor, Fair, Good, Excellent
8. Previous Maintenance	Low, Normal, High

9. Effect on Mission (Comments): ______________________________

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Figure 3. Airfield Pavement Condition Evaluation Summary.

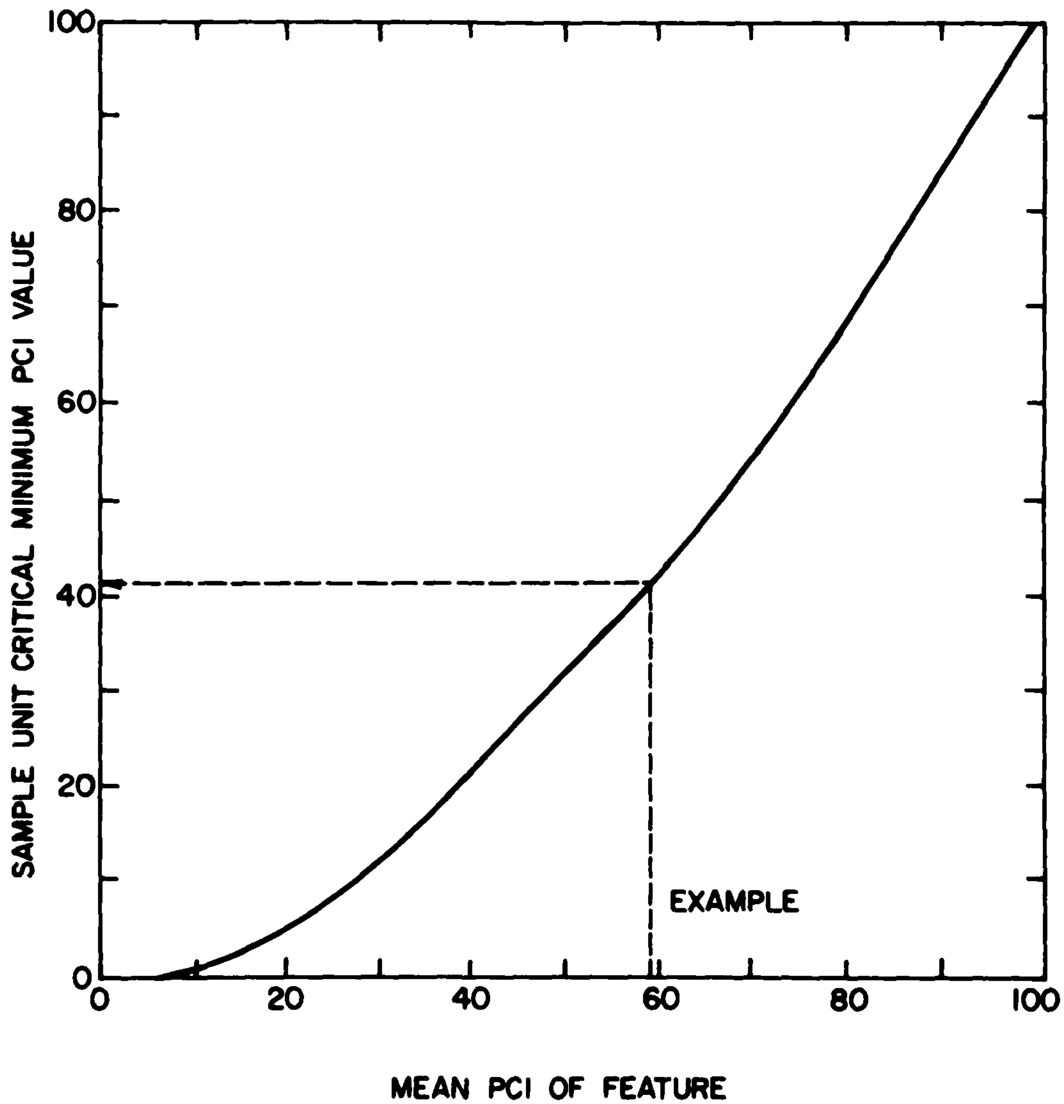

Figure 4. Procedure to Determine Critical Minimum Sample Unit PCI Based on Mean PCI of Feature.

Rate of Deterioration

The rate of long-term deterioration is determined from Figures 5 through 8 for jointed concrete pavements, asphalt overlay over concrete, asphalt pavements (no overlays), and asphalt pavement that received overlays. These graphs were developed based on data from pavement features surveyed during FY76 to 78. The features, located at airfields throughout the United States (Figure 9), were subjected to a variety of traffic and climatic conditions. The hatched area in each graph envelops the majority of data points that represent normal rates of deterioration actually occurring in the field. A pavement feature above the hatched area is considered to have a low rate of deterioration, and a feature below the hatched area is considered to have a high rate of deterioration.

The pavement's rate of deterioration must also be checked based on a short-term or yearly loss of PCI. Whenever the mean PCI of a feature (assuming that only routine M&R is applied) decreases by seven or more PCI points, the rate of deterioration should be considered high. If the loss in PCI is four to six points, the short-term rate of deterioration should be considered normal or average.

Pavement Distress

Examination of specific distress types, severities, and quantities provides a valuable aid in determining the cause of pavement deterioration, its condition, and eventually its M&R needs. Figures 10 and 11 generally classify distress types for concrete- and asphalt-surfaced pavements according to cause and effect on condition. Conditions at each pavement will dictate which distresses will be placed in each group.

For evaluation purposes (Figure 3), distresses have been classified into three groups based on cause: (1) load associated, (2) climate/durability associated, and (3) those caused by other factors. In addition, the effect of drainage on distress occurrence should always be investigated.

The following steps are a procedure for determining the primary cause or causes of pavement condition deterioration for a given feature:

1. The total deduct values attributable to load, climate/durability, and other associated distress are determined separately. For example, the following distresses were measured on an asphalt feature and the deduct values determined (see p 18):

Distress Type	Severity	Overall Density for Feature
Alligator cracking	Medium	6.4
Transverse cracking	Low	2.0
Rutting	Low	2.7

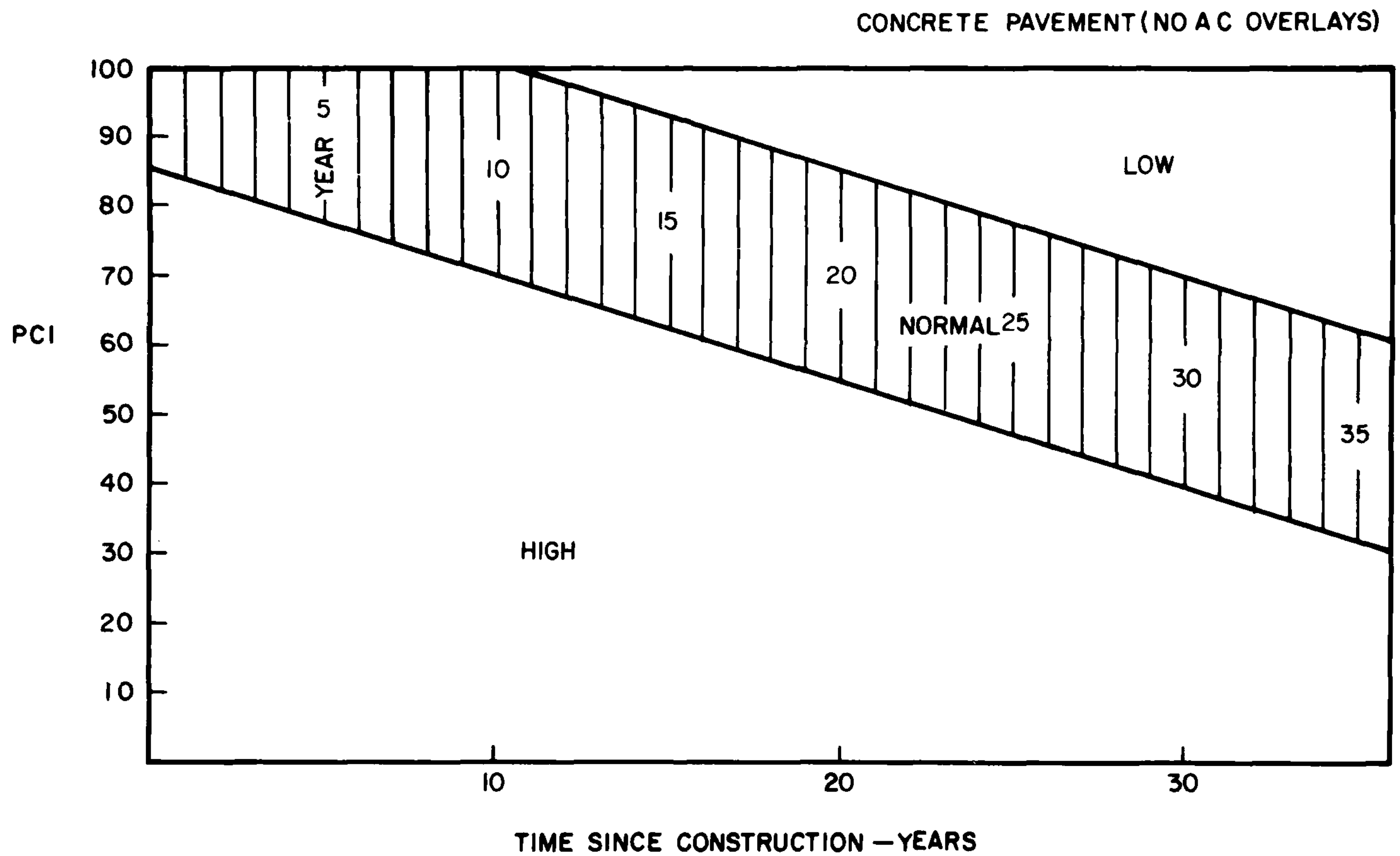

Figure 5. Rate of Deterioration of Jointed-Concrete-Surfaced Airfield Pavements.

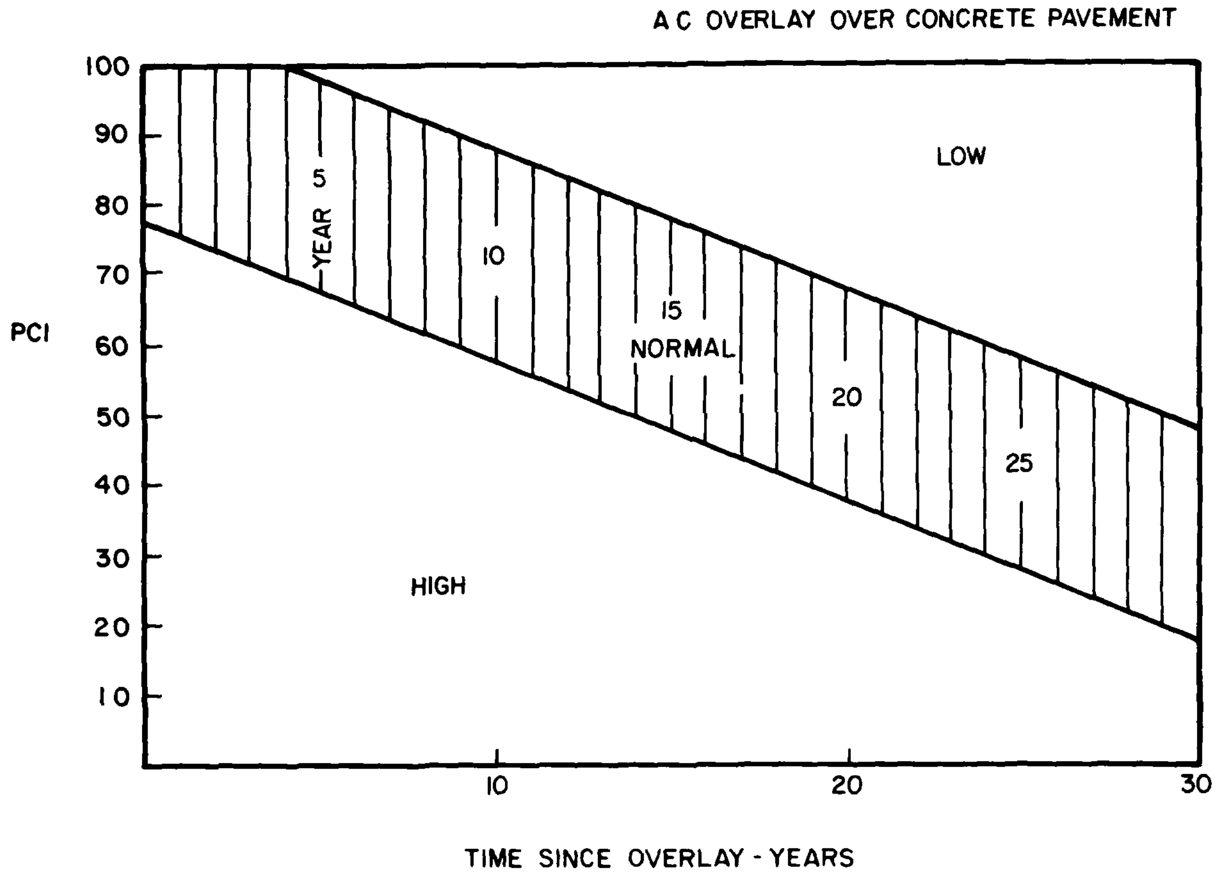

Figure 6. Rate of Deterioration of Concrete Pavements Overlaid With AC.

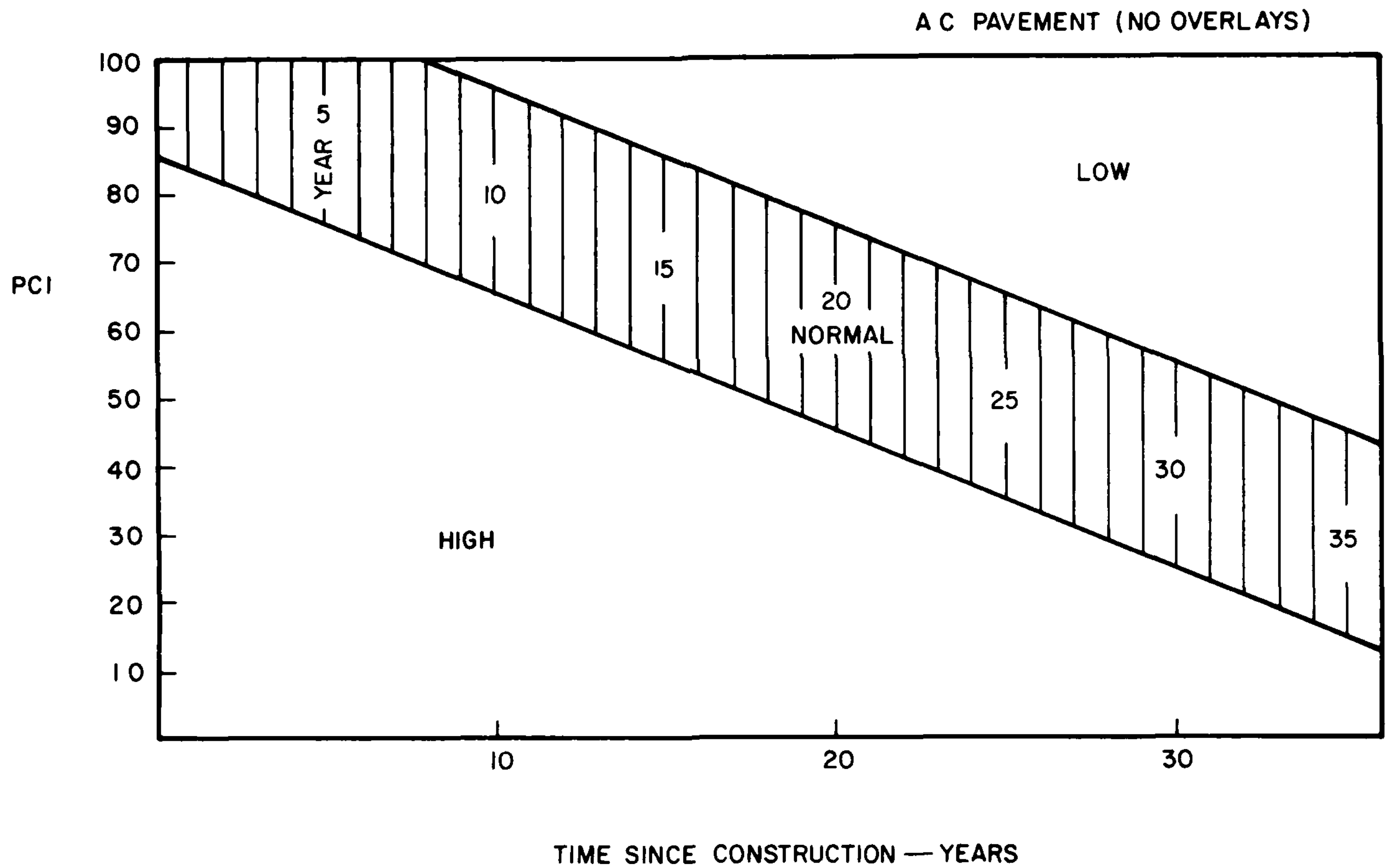

Figure 7. Rate of Deterioration of AC Pavements (No Overlays).

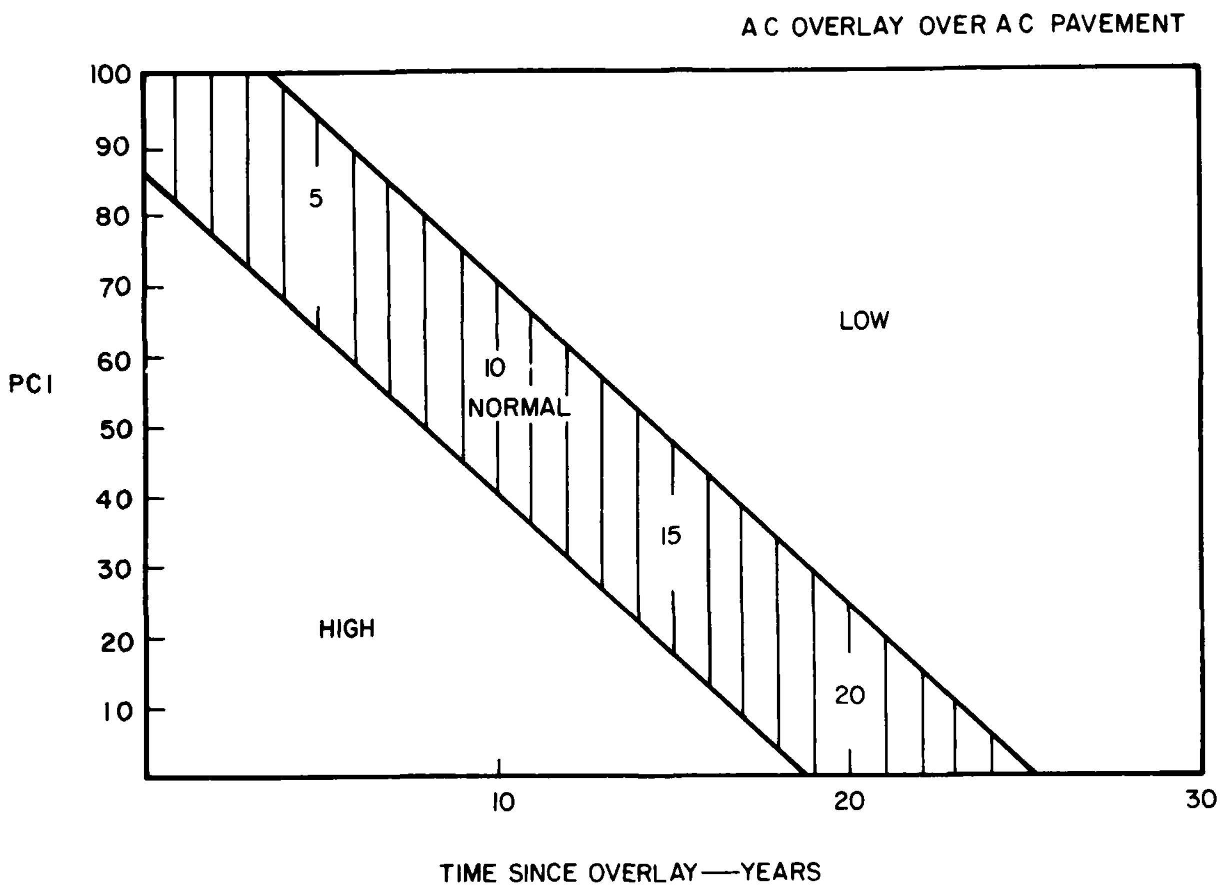

Figure 8. Rate of Deterioration of AC Pavements That Have Been Overlaid.

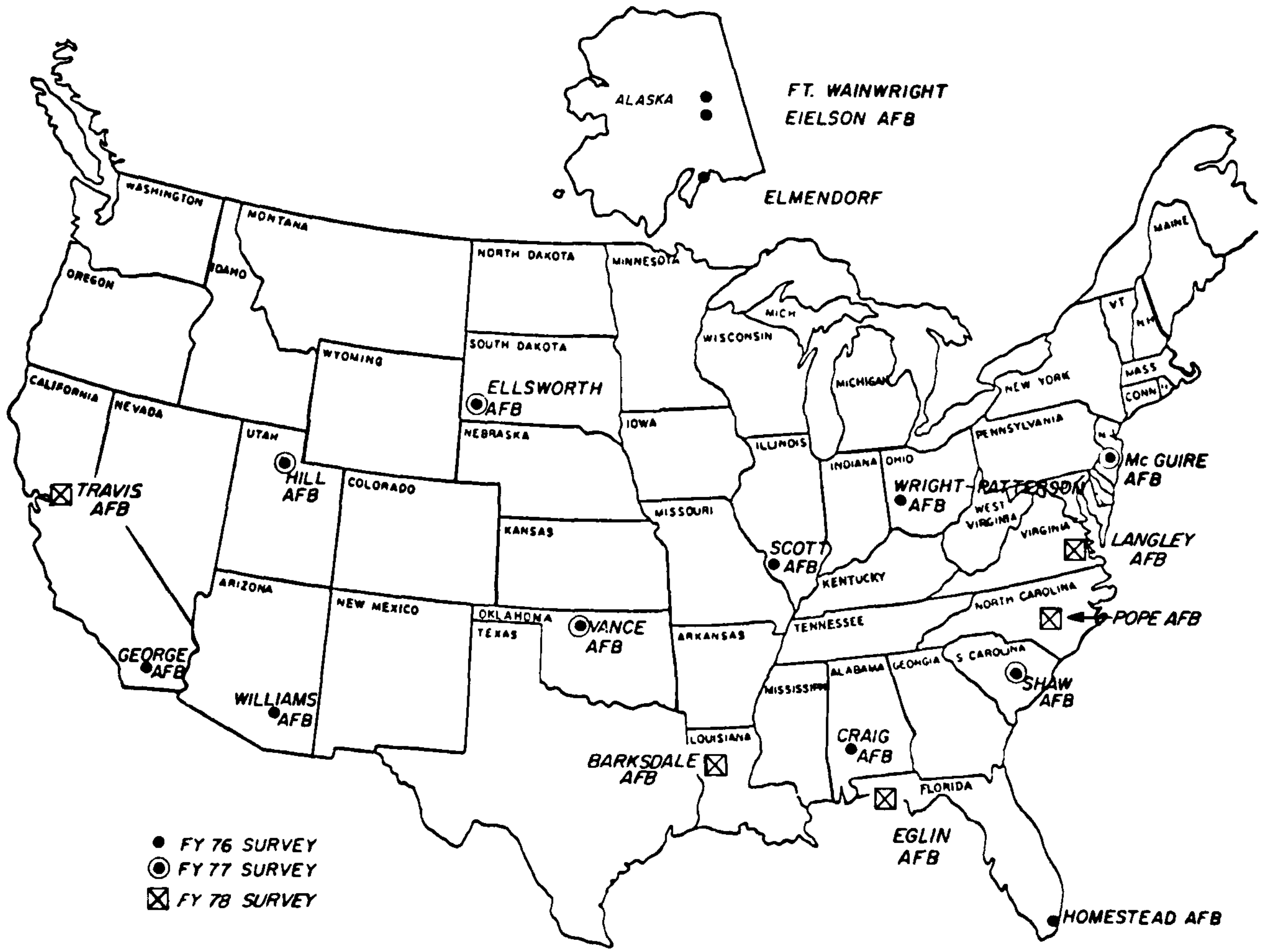

Figure 9. Airfields From Which Data Were Collected for Development of Rate of Deterioration.

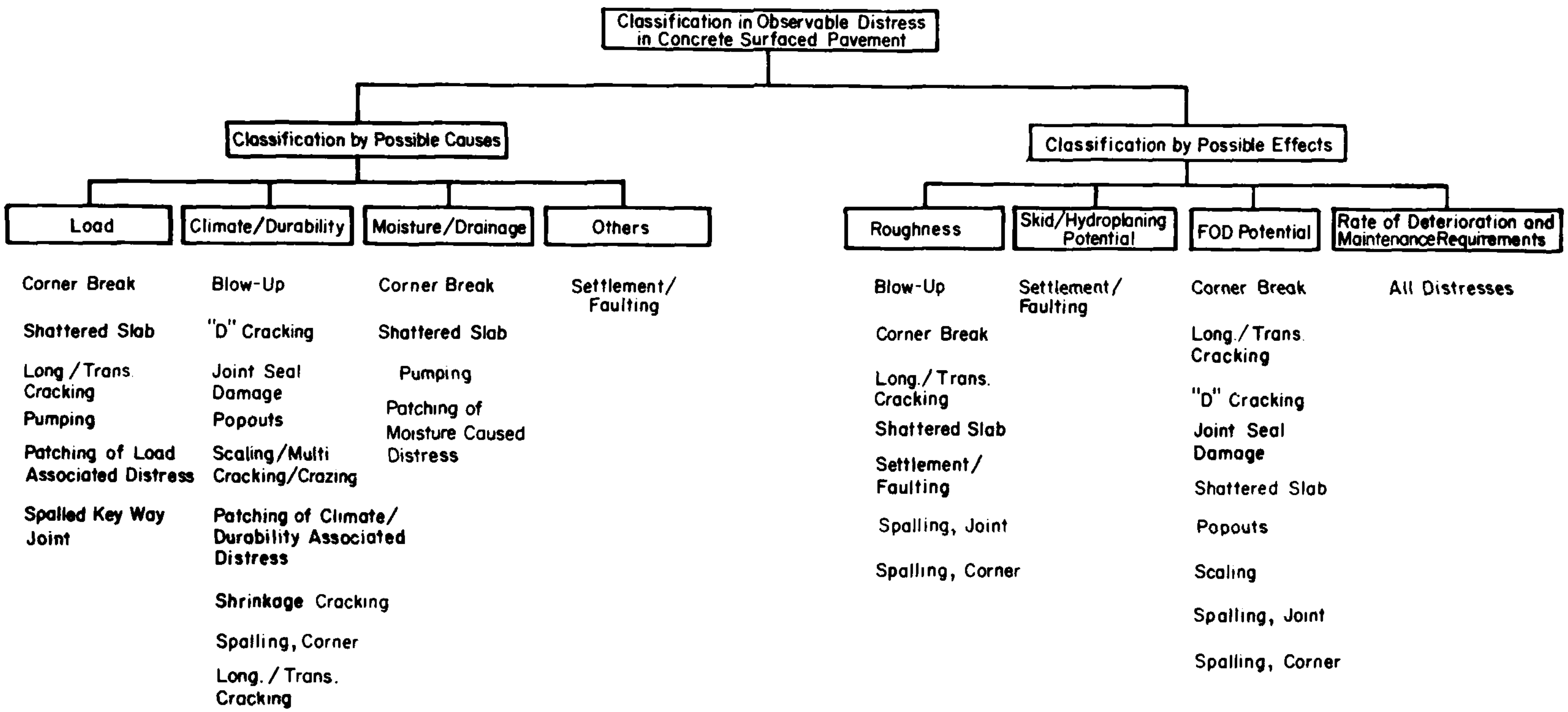

Figure 10. General Classification of Concrete Distress Types Based on Causes and Effect on Conditions. Conditions at Each Pavement Will Dictate What Specific Distresses Go Into Each Group.

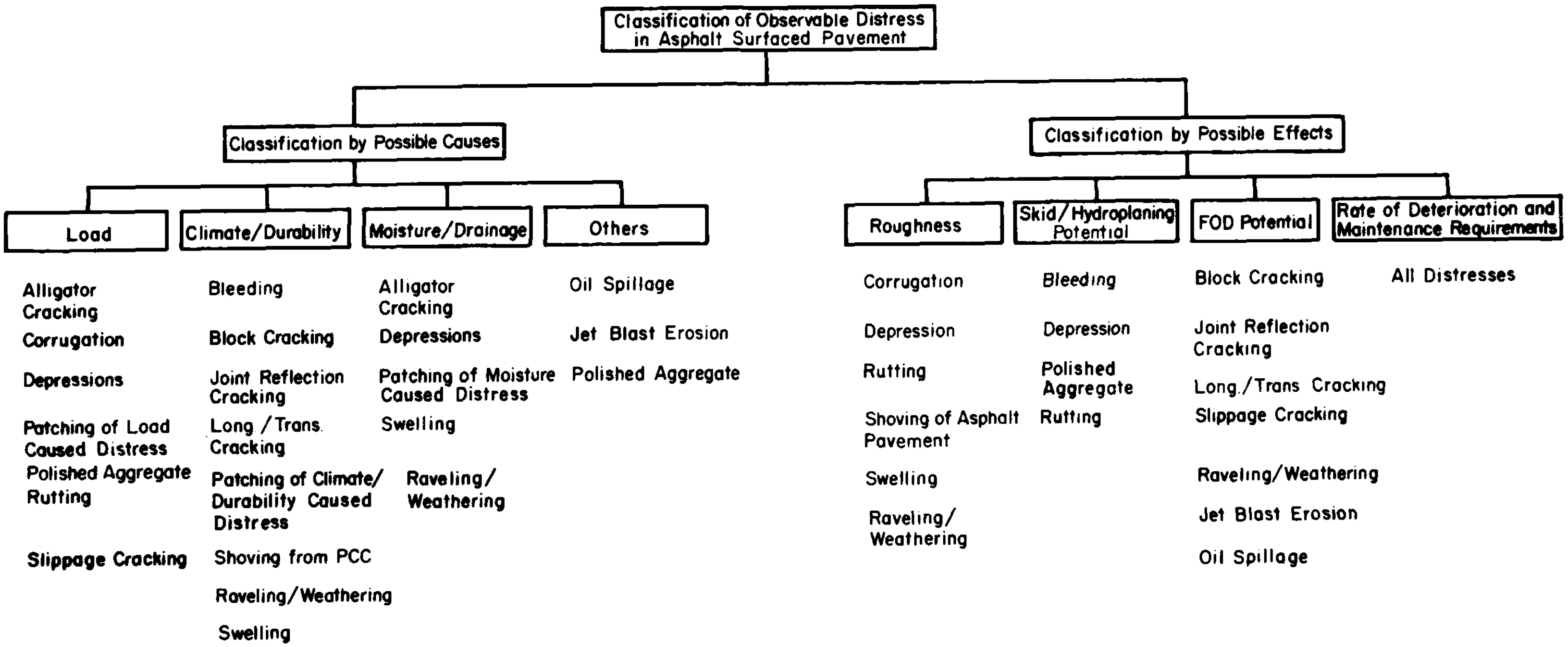

Figure 11. General Classification of Asphalt Distress Types Based on Causes and Effects on Conditions. Conditions at Each Pavement Will Dictate What Specific Distresses Go Into Each Group.

Distress Type	Deduct Value	Cause
Alligator cracking	50	Load
Transverse cracking	8	Climate/durability
Rutting	20	Load

The total deduct value attributable to load is 70, and the total deduct value attributable to climate/durability is 8.

2. The percentage of deducts attributable to load, climate/durability, and other causes is computed. For the above example feature, the calculation is as follows:

$$\text{Load} = 70/78 \times 100 = 90 \text{ percent}$$

$$\text{Climate/Durability} = 8/78 \times 100 = 10 \text{ percent}$$

$$\text{Total} = 100 \text{ percent}$$

3. The percent deduct values attributed to each cause are the basis for determining the primary cause(s) of pavement deterioration. In this example, distresses caused primarily by load have resulted in 90 percent of the total deducts, whereas all other causes have produced only 10 percent. Thus, traffic load is by far the major cause of deterioration for this pavement feature.

A study should also be made of the pavement drainage situation. If moisture is causing accelerated deterioration of the pavement, the engineer must determine how it is happening and why (groundwater table, infiltration of surface water, ponding water on the pavement, etc.). If moisture is contributing significantly to the rate of pavement condition deterioration, ways must be found to prevent or minimize this problem. For example, when a concrete taxiway was initially evaluated (during field visits), the PCI showed that the long-term rate of deterioration was high. However, re-examination of the pavement showed that pumping occurred along most of the joints.

Load-Carrying Capacity Evaluation

An airfield pavement's load-carrying capacity is defined in terms of three factors: (1) the aircraft gross weight, (2) the aircraft type, and (3) the number of aircraft passes over the pavement until a "failed" condition is predicted. If these three factors remain constant, the load-carrying capacity depends on the pavement structure, material properties, and subgrade soil properties. A series of pavement evaluation curves has been developed by the Waterways Experiment Station (WES) for both flexible (asphalt) and rigid (concrete) pavements for most aircraft types and are provided in Chapters 2 and 3 of AFM 88-24 (1979 version) (Reference 5). Table 1 gives the definitions of pass intensity level used in load-carrying determinations by the Air Force.

TABLE 1. DEFINITIONS OF PASS INTENSITY LEVELS USED IN LOAD-CARRYING CAPACITY EVALUATION*

Pass Intensity Level		
I	300,000 passes for AGI**	1-3
	50,000 passes for AGI	4-10
	15,000 passes for AGI	11-13
II	50,000 passes for AGI	1-3
	15,000 passes for AGI	4-10
	3,000 passes for AGI	11-13
III	15,000 passes for AGI	1-3
	3,000 passes for AGI	4-10
	500 passes for AGI	11-13
IV	3,000 passes for AGI	1-3
	500 passes for AGI	4-10
	100 passes for AGI	11-13

*This table adapted from Airfield Pavement, AFM 88-24, Chapters 2 and 3 (Department of the Air Force, 1979).

**AIRCRAFT GROUP INDEX

1	2	3	4	5	6	7	8	9	10	11	12	13
C-123	A-7	F-111	C-130	C-7	B-737	B-727	B-707	C-141	C-5	B-747	B-52	KC-10A
	A-10			C-9	T-43	KC-97	E-3			E-4		DC-10
	A-37											L-1011
	F-4			DC-9	C-199		C-135					
	F-5			C-54	EC-121		KC-135					
	F-14			C-131			VC-137					
	F-15			C-140								
	F-16			T-29								
	F-100											
	F-101											
	F-102											
	F-105											
	F-106											
	T-33											
	T-37											
	A-37											
	T-38											
	T-39											

Figures 12 and 13 give sample curves for DC-9 aircraft for rigid and flexible pavements. The following information is needed to use the concrete evaluation curves (example data are provided):

	Example
Type of traffic area*	A
Concrete flexural strength (psi)	700
Modulus of subgrade support (k)--lb/cu in.	25
Gross aircraft weight (kips)	125
PCC slab thickness (inches)	12

The number of DC-9 aircraft passes over the feature to initial cracking is determined from Figure 12. Using the example data, 80 passes are obtained.

The following information is needed to use the asphalt (or flexible) pavement curves (example data are provided):

	Example
Type of traffic area	A
Thickness of pavement structure (inches)	21
Gross aircraft weight (kips)	100
CBR of subgrade (percent)	4

The number of DC-9 aircraft passes to initial cracking is determined from Figure 13. Using the example data, 920 passes are obtained. It is important to realize that pavement performance is highly variable and that these curves are conservative; pavements may carry more traffic to initial cracking than the curves indicate.

A pavement feature can be evaluated for its load-carrying capacity using the following procedure:

1. Determine the pavement structure and material properties (including subgrade) required.

2. Estimate the number of passes over the feature of each major aircraft since the feature was constructed (call these n_i).

3. Determine the allowable number of aircraft passes to initial cracking using the evaluation curves for each aircraft type (i.e., Figures 12 and 13; (call these N_i).

4. Determine whether the pavement load-carrying capacity has been exceeded by any aircraft (i.e., when $n_i > N_i$).

Research is under way to develop nondestructive testing methods and criteria for evaluating the load-carrying capacity of airfield pavements. The results of this development (when successful) may be used to replace the procedure outlined in this subsection.

*Pavements are classified into traffic areas A, B, C, or D according to Air Force Manual No. 88-6, Chapter 1.

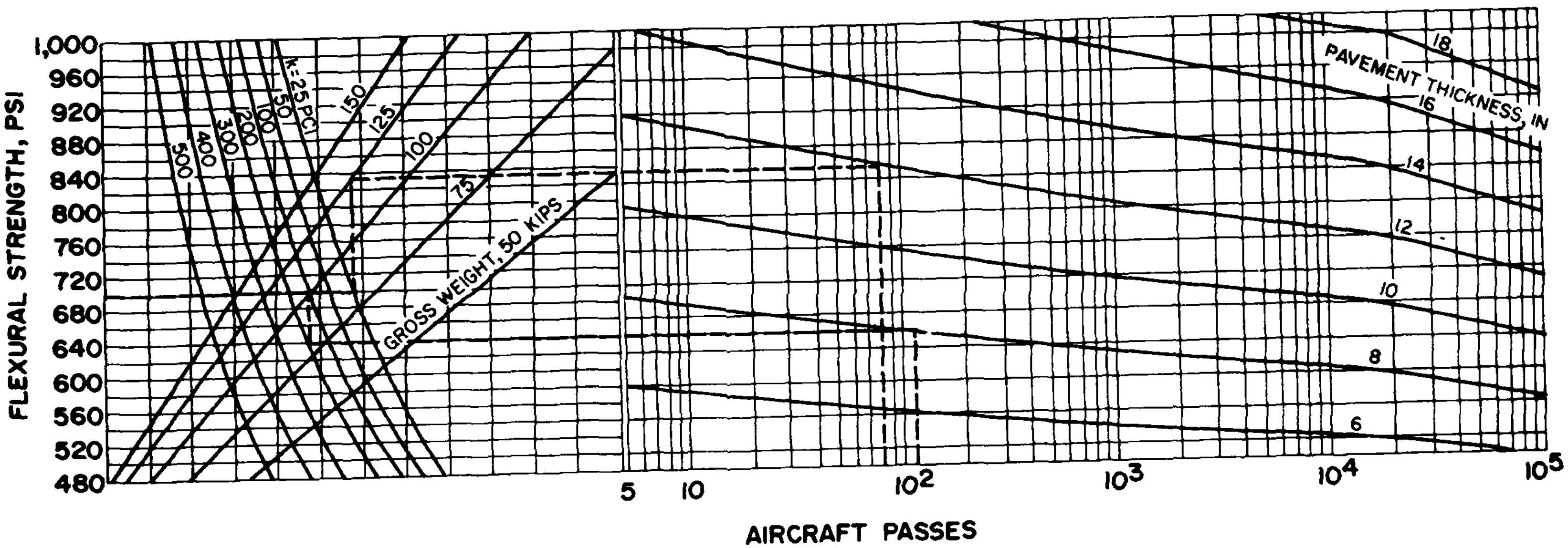

Figure 12. Rigid Pavement Evaluation Curves, DC-9, Type A Traffic Areas.

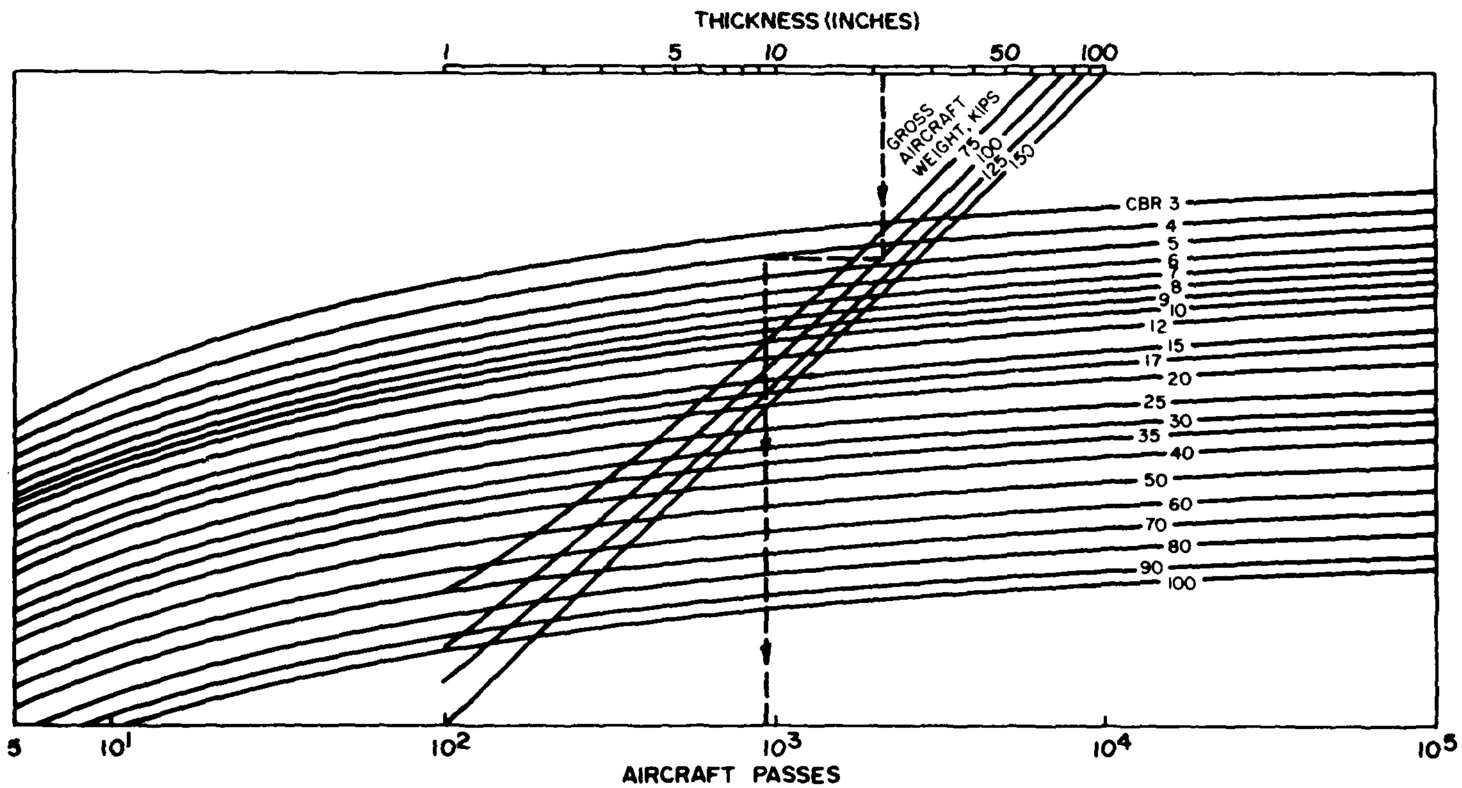

Figure 13. Flexible Pavement Evaluation Curves, DC-9, Type A Traffic Areas.

Surface Roughness

There are three ways to estimate surface roughness. First, pilot complaints are considered to be subjective but highly reliable sources of qualitative roughness information. These reports reflect aircraft ride quality as well as surface roughness; therefore, the additional factor of aircraft vibration is included.

Second, certain distress types contained in the PCI may be correlated with localized roughness, as shown in Figures 10 and 11. However, experience has indicated that it is difficult or impossible to see the longer wavelengths which affect aircraft ride quality while inspecting a runway surface.

Third, the roughness may be quantitatively evaluated on a relative basis by analyzing measured profile elevation data. The development of this approach formed a large part of a joint Federal Aviation Administration (FAA) and Air Force research program (Reference 6). This method requires the development of rapid elevation-measuring instruments and suitable data-processing techniques involving filtering and statistical analysis of random data. The use of computer programming to estimate aircraft vibration response is also required.

Both PCI and surface elevation data were measured for several features at two airfields. A statistical regression and correlation analysis was used on these data to determine whether PCI could be used to estimate roughness (or vice versa) (Reference 6). Some significant correlation was observed from the available data, which indicated that the lower the mean feature PCI, the higher the root mean square of elevation data (roughness), provided the roughness was not built into the pavement during construction.

Skid Resistance Hydroplaning Potential

Pavement skid resistance as measured by the Air Force (Reference 7) is reported in terms of the coefficient of friction (MU) determined from the Mu-Meter, and the wet-to-dry stopping distance ratio (SDR) measured by a diagonally braked vehicle (References 8 and 9).

Research data were used to develop breakpoints in the values of MU and SDR in order to define potential hydroplaning problems. Table 2 summarizes the evaluation ratings. Transverse slope measurements were also made along both sides of the runway centerline to indicate the runway surface's drainage characteristics. Slopes downward from the centerline indicate that water drains to the runway edge; an upward slope indicates that the drainage crosses the runway centerline before draining to the edge. Recommended guidelines indicate that surface slopes in excess of 1 percent promote good to excellent drainage conditions; the drainage characteristics of the runway are rated in terms of this general statement (Reference 7). Measurement of the transverse slope can also be accomplished through standardized survey techniques.

Measurements are required to adequately evaluate the skid resistance/hydroplaning characteristics of a runway. Periodic evaluation at approximately 5-year intervals is the current Air Force procedure. However, if the appropriate equipment is not available, the engineer can make an approximate visual

TABLE 2. EVALUATION RATINGS

Mu-Meter Airfield Pavement Rating*

MU	Expected Aircraft Braking Response	Response
Greater than 0.50	Good	No hydroplaning problems are expected
0.42 - 0.50	Fair	Transitional
0.25 - 0.41	Marginal	Potential for hydroplaning for some aircraft exists under certain wet conditions
Less than 0.25	Unacceptable	Very high probability for most aircraft to hydroplane

Stopping Distance Ratio Airfield Pavement Rating (Diagonally Braked Vehicle)**

SDR	Hydroplaning Potential
1.0 - 2.5	No hydroplaning anticipated
2.5 - 3.2	Potential not well defined
3.2 - 4.4	Potential for hydroplaning
Greater than 4.4	Very high hydroplaning potential

* From G. D. Ballentine, The Air Force Weapons Laboratory Skid Resistance Research Program, 1969-1974, Final Report AFWL-TR-74-181 (Air Force Weapons Laboratory, 1975).

** Adapted from Ballentine; source of ratings adjusted to reflect use of 15-inch tires on the diagonally braked vehicle. Values shown are subject to revision.

evaluation. Figures 10 and 11 list the types of distress that cause skid resistance/hydroplaning problems on asphalt- and concrete-surfaced pavements. The engineer should remember that any decision based on observable distress alone is only judgmental.

Previous M&R Applied

A pavement feature can be kept in operating condition almost indefinitely if extensive M&R is applied continually. However, there are major drawbacks to this maintenance strategy, such as overall cost, downtime of feature, increase in roughness caused by excessive patching, limitations of manpower and equipment, and airfield mission requirements. The amount and types of previous M&R applied to a pavement feature are important factors in deciding what type of M&R is needed. A pavement having a large portion which has been patched or replaced must have had many previous distress problems which are likely to continue in the future.

Permanent patching of asphalt pavements and large areas of patching (over 5 square feet) and/or slab replacement of concrete pavement may be used as criteria for evaluating previous maintenance. Patching and/or slab replacement ranging between 1.5 to 3.5 percent (based on surface area for asphalt and number of slabs for concrete) is considered normal; more than 3.5 percent is considered high, and less than 1.5 percent is considered low. Some pavement features may have received an excessive amount of M&R other than patching. If the engineer feels that a feature should be evaluated as having high previous maintenance, then this evaluation should take precedence over evaluation criteria based on only patching and slab replacement.

EFFECT ON MISSION

Constraints and/or policy imposed by mission on M&R alternative selection should be identified. Types of constraints include facility (such as runway), closure time, Foreign Object Damage (FOD) potential, and possible change in mission aircraft.

For example, in areas where FOD potential represents a severe problem, the alternative of applying a surface aggregate seal coat should be avoided even though it may be the most economical solution. Similarly, if an M&R alternative requires temporary relocation of mission, either the cost of relocation should be considered, or the alternative should be considered as unfeasible and avoided.

SECTION IV

GUIDELINES FOR SELECTION OF FEASIBLE M&R ALTERNATIVES

This section provides guidelines for selecting feasible M&R alternatives based on results of the pavement evaluation process described in Section III. M&R alternatives are first categorized into three groups: routine, major, and overall. The guidelines are procedures for selecting the optimum category, and then identifying feasible alternatives.

DEFINITION OF M&R CATEGORIES

M&R can be divided into three general categories for convenience of analysis and discussion.

Routine M&R

Routine M&R, which is preventive and/or minor localized M&R, includes methods that preserve pavement condition and retard its deterioration. These methods include crack sealing, joint sealing, application of fog seals and rejuvenators, any amount of skin patching, application of heat and rolling sand, placement of small patches for concrete (less than 5 square feet), and patching of joint and corner spalls. However, partial-depth or full-depth patching, slab replacement, slab undersealing, slab jacking, and slab grinding are considered routine only if they are applied to a small area of the pavement feature (usually less than 3.5 percent).

Major Localized M&R

Major localized M&R, an extended form of localized M&R, includes partial-depth or full-depth patching, slab replacement, slab undersealing, and slab grinding. These methods are considered to be major localized M&R only when they are applied to a large area or portion of the pavement feature (usually more than 3.5 percent of the feature). Other M&R methods included in this category are application of aggregate seal over the entire feature and the reconstruction of many joints in a concrete pavement.

Overall M&R

Overall M&R covers the entire pavement feature and usually improves its load-carrying capacity. This category includes overlaying with asphalt or concrete, reprocessing or recycling of existing pavements, and total reconstruction.

M&R GUIDELINES

Excellent correlation was observed between the PCI and M&R categories. The correlation was based on results obtained for 37 airfield pavement features, using the consensus of 10 experienced pavement engineers. The 37 pavement features consisted of runways, taxiways, and aprons and represented a wide variety of climates, traffic, ages, and structure. Eighteen of the features were asphalt- or tar-surfaced pavements; 19 were jointed concrete. During the field surveys, all existing distress was measured, 35-mm color slides were taken, pavement structure and age were determined, and the primary aircraft using each feature was identified. The engineers used this information as a basis for making M&R decisions. (The PCIs for these features were not available to the engineers when they were recommending M&R requirements.)

Figure 14 summarizes the results of the engineers' decisions. The vertical axis is the percentage of engineers recommending routine, major, or overall M&R within the next 2 years of the pavement's life, and the horizontal axis is the pavement condition rating. These results show that the higher the PCI (condition rating), the greater the percentage of engineers selecting only routine M&R; and the lower the PCI, the greater the percentage of engineers choosing overall M&R. In the middle of the PCI scale (40 to 70), there was a lack of consensus.

Based on these results, four M&R zones were established to provide guidelines for selecting M&R. As shown in Figure 15, these zones conveniently fit the condition rating zones used with the PCI. The four zones are described in the following paragraphs.

Routine M&R (R-Zone)

For this zone, nearly all the engineers recommended only routine M&R over the next 2 years. Determinations of the specific routine M&R methods were based on distress types and severities, as presented in Tables 3 and 4. Major or overall M&R would only be recommended in exceptional cases and where the pavement condition evaluation (Figure 3) indicates that one or more of the following conditions exists:

1. Load-associated distress accounts for a majority of the distress deduct value

2. Load-carrying capacity is deficient, as indicated by a "Yes" rating

3. Rate of pavement deterioration is rated high

4. Previous M&R applied is rated high

5. Surface roughness is rated major

6. Skid resistance/hydroplaning potential is rated very high

7. A change in mission requires greater load-carrying capacity.

Thus, the pavement engineer should concentrate on applying routine M&R to pavement features within this zone. Timely and effective routine M&R will reduce the rate of pavement deterioration.

Routine Major Overall Zone (R-M-O Zone)

This zone includes all pavement features having PCIs ranging between 41 and 70, or a condition rating of "fair" and "good." Figure 14 shows that

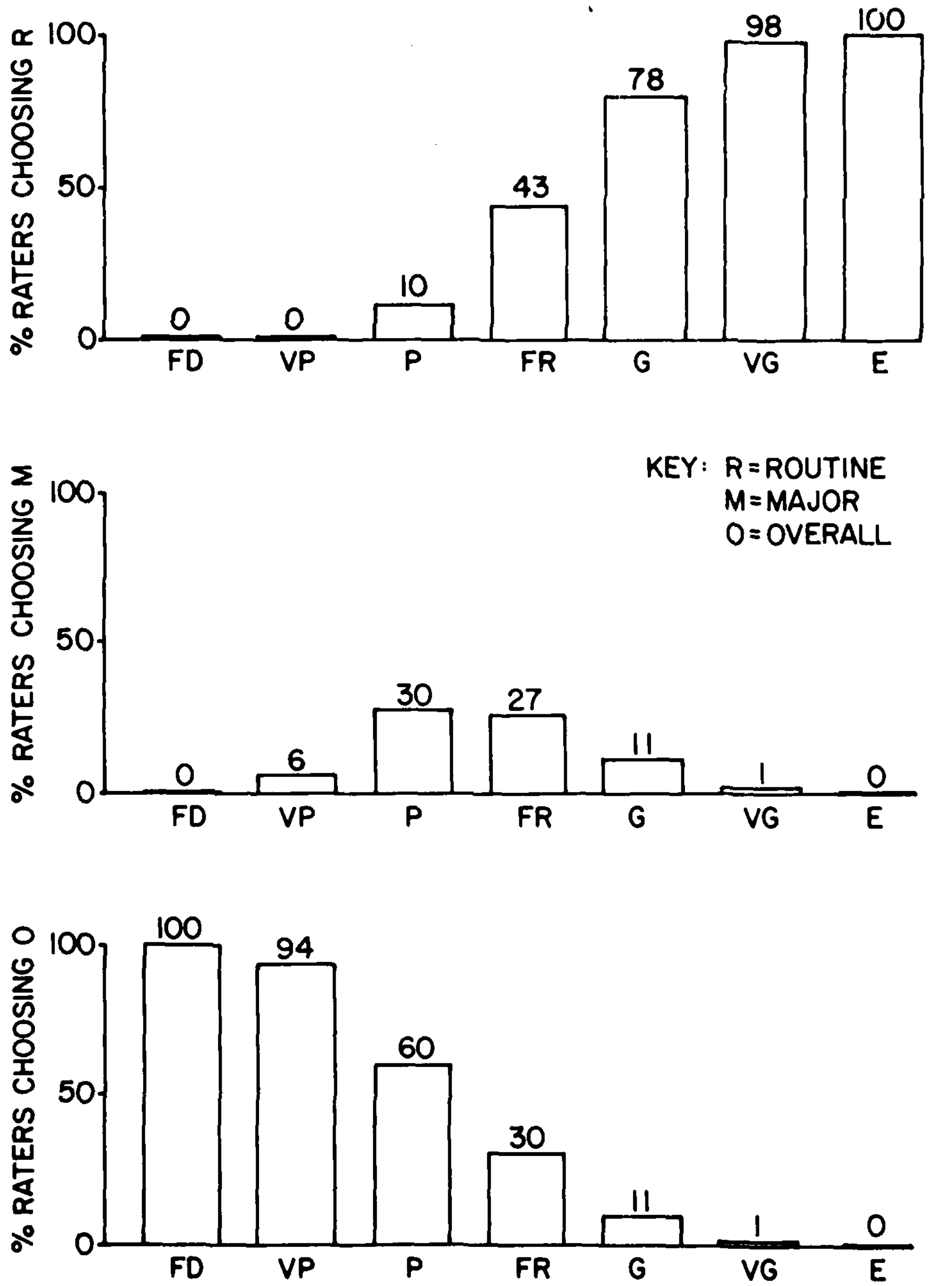

Figure 14. Percentage of Engineers Sel-cting Routine, Major, and Overall M&R Within 2 Years Versus Pavement Condition Rating.

M & R ZONE	PCI		RATING
ROUTINE	100		EXCELLENT
	85		VERY GOOD
ROUTINE, MAJOR, OVERALL,	70		GOOD
	55		FAIR
MAJOR, OVERALL	40		POOR
OVERALL	25		VERY POOR
	10		FAILED
	0		

Figure 15. Correlation of M&R Zones With PCI and Condition Rating.

TABLE 3. ALTERNATIVES FOR PREVENTIVE AND LOCALIZED M&R METHODS FOR JOINTED CONCRETE SURFACED AIRFIELD PAVEMENTS

DIST TYPE \ M&R METHOD	DO NOTHING	CRACK SEALING	JOINT SEALING	PARTIAL DEPTH PATCH (BONDED)	FULL DEPTH PATCH	SLAB REPLACE-MENT	UNDER-SEAL	GRINDING SLAB	SLAB JACK-GROUT	NOTES
1 Blow-up				L*, M*	H*	H*				*Must provide expansion joint
2 Corner Break	L	L, M, H			M, H					
3 Long/Trans/ Diag. Crk	L	L, M, H		H*	H	H				*Allow crack to continue through patch except when using AC
4 "D" Crk	L	L*	L*	M, H	M, H	H				*If "D" crk exists, seal all joints and cracks
5 Joint Seal Damage	L		M*, H							*Joint seal local areas
6 Small Patch less than 5 ft	L	M		M*, H*	H*					*Replace patch
7 Large Patch greater than 5 ft	L	M		M*, H*	H*	H				*Replace patch
8 Popouts	A									
9 Pumping		A	A				A			
10 Crazing/ Sealing	L			M, H		H*				*Only when surface is unacceptable
11 Settlement/ Faulting	L					H		M, H	M, H	
12 Divided Slab		L, M, H				M, H				
13 Shrinkage Crk	A									
14 Spalling Joint	L		L, M	L, M, H	M, H*	M, H*				*If caused by keyway failure, provide load transfer
15 Spalling Corner	L		L, M	M, H						

A = distress type having only one severity level
L = distress at low severity
M = distress at medium severity
H = distress at high severity

TABLE 4. ALTERNATIVES FOR PREVENTIVE AND LOCALIZED M&R METHODS FOR ASPHALT- OR TAR-SURFACED AIRFIELD PAVEMENTS

	Dist. Type \ M&R METHOD	Do Nothing	Crack Seal	Partial Depth Patch	Full Depth Patch	Skin Patch	Apply Heat and Roll Sand	Apply ** Surface Seal (Emulsion)	Apply † Rejuvenator	Apply Agg. Seal Coat	NOTES
1	Allig. Crk			M, H	M, H			L	L		
2	Bleeding	A					A				
3	Block Cr.	L	L, M, H						L	L, M	
4	Corrugation	L		M, H	M, H						
5	Depression	L		M, H	M, H	M, H					
6	Jet Blast	A		A		A		A		A	
7	Jt. Reflection Crk	L	L, M, H	H							
8	Long. & Trans. Crk.	L	L, M, H	H					L	L, M	
9	Oil Spillage	A		A	A						
10	Patching	L	M	H*	H*						*Replace patch
11	Polished Agg.	A								A	
12	Raveling/ Weathering	L		H				L, M	L	M, H	
13	Rutting	L		M, H	M, H	M, H					
14	Shoving	L		M, H							
15	Slippage Crk.	A		A							
16	Swell	L			M, H						

A = distress types having one severity level
L = distress at low severity
M = distress at medium severity
H = distress at high severity
**= fog seal or slurry seal shall not be used on runway pavements without prior approval by Command Pavement Engineer
† = Based on Major Command approval

there was general disagreement among the engineers concerning which type of M&R should be applied. Generally, however, the higher the PCI in this zone, the higher the percentage of engineers recommending routine M&R. It is therefore recommended that either routine or major M&R generally be applied to pavement features in this zone (particularly for those having a "good" rating). The specific routine or major M&R alternative selected will depend on the type of distress and severities, as presented in Tables 3 and 4.

Overall M&R should be considered only if the condition evaluation indicates that one or more of the items listed exist in 1 through 7 in the R-Zone description above. Conditions for each specific pavement will dictate feasible overall M&R alternatives. Table 5 lists various types of overall M&R methods.

Major Overall Zone (M-O Zone)

This zone includes all pavement features having PCIs ranging between 26 and 40, or a condition rating of "poor." Figure 14 shows that the consensus among the engineers indicates that pavement features in this condition should receive either major or overall M&R within the next 2 years. For example, 80 percent of the engineers recommended one feature having a PCI of 35 for overall M&R, while 20 percent recommended major M&R (none recommended routine M&R). Some engineers apparently felt that a pavement in this condition needs significant M&R to prevent it from exceeding the point of economical repair, while many others felt that it has already exceeded that point. The decision to select major or overall M&R should be primarily based on an economic analysis of the alternatives. However, if the condition evaluation indicates that one or more of items 1 through 7 exist, overall M&R should be strongly considered. Tables 3, 4, and 5 present guidelines for selecting specific alternatives.

Overall Zone (O-Zone)

This zone includes all pavement features having PCIs ranging between 0 and 25, with a condition rating of "very poor" or "failed." Figure 14 shows that there was a consensus among the engineers that pavement features in this condition should receive only overall M&R within the next 2 years. The experienced engineers apparently felt that a pavement feature in this condition is beyond the point of economical repair and that only an overall M&R would provide adequate results. Table 5 lists various overall M&R methods. Determination of feasible alternatives is based on conditions specific to each pavement. Determination of which overall M&R alternative to select should be based on an economic analysis of the feasible alternatives.

TABLE 5. TYPES OF OVERALL REPAIR

Jointed-Concrete-Surfaced Pavements

1. Overlay with unbonded, partially bonded, or fully bonded Portland cement concrete (rigid overlay).

2. Overlay with all-bituminous or flexible overlay (nonrigid overlay).

3. Portland cement concrete pavement recycling* -- a process by which an existing Portland cement concrete pavement is processed into aggregate and sand sizes, then used in place of, or in some instances with additions of conventional aggregates and sand, into a new mix and placed as a new Portland cement concrete pavement.

4. Pulverize existing surface in place, compact with heavy rollers, place aggregate on top, and overlay.

5. Replace keel section, i.e., remove central portion of pavement feature (subjected to much higher percentage of traffic coverages than rest of pavement width) and replace with new pavement structure.

6. Reconstruct by removing existing pavement structure and replacing with a new one.

7. Grind off thin layer of surface if predominant distress is scaling or other surface distresses; overlay may or may not be applied.

8. Groove surface if poor skid resistance/hydroplaning potential is the main reason for overall M&R.

Asphalt- or Tar-Surfaced Pavements

1 Overlay with all-bituminous or flexible overlay.

2. Overlay with Portland cement concrete (rigid overlay).

3. Hot-mix asphalt pavement recycling* -- one of several methods where the major portion of the existing pavement structure (including, in some cases, the underlying untreated base material) is removed, sized, and mixed hot with added asphalt cement at a central plant. The process may also include the addition of new aggregate and/or a softening agent. The finished product is a hot-mix asphalt base, binder, or surface course.

*Initiation of National Experimental and Evaluation Program (NEEP) Project No. 22, Pavement Recycling, Notice N 5080.64 (Federal Highway Administration [FHWA] June 3, 1977).

TABLE 5. TYPES OF OVERALL REPAIR (CONCLUDED)

4. Cold-mix asphalt pavement recycling* -- one of several methods where the entire existing pavement structure (including, in some cases, the underlying untreated base material) is processed in place or removed and processed at a central plant. The materials are mixed cold and can be reused as an aggregate base, or asphalt and/or other materials can be added during mixing to provide a higher-strength base. This process requires use of an asphalt surface course or surface seal coat.

5. Asphalt pavement surface recycling* -- one of several methods where the surface of an existing asphalt pavement is planed, milled, or heated in place. In the latter case, the pavement may be scarified, remixed, relaid, and rolled. In addition, asphalts, softening agents, minimal amounts of new asphalt hot-mix, aggregates, or combinations of these may be added to obtain desirable mixture and surface characteristics. The finished product may be used as the final surface, or may, in some instances, be overlaid with an asphalt surface course.

6. Apply a porous friction course to restore skid resistance and eliminate hydroplaning potential.

7. Replace keel section, i.e., remove central portion of pavement feature (subjected to much higher percentage of traffic coverage than rest of pavement width) and replace with new pavement structure.

8. Reconstruct by removing existing pavement structure and replacing with a new one.

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*Initiation of National Experimental and Evaluation Program (NEEP) Project No. 22, Pavement Recycling, Notice N 5080.64 (Federal Highway Administration [FHWA] June 3, 1977).

SECTION V

PROCEDURE FOR PERFORMING ECONOMIC ANALYSIS AMONG M&R ALTERNATIVES

The results of the pavement condition evaluation and the guidelines for M&R selection may indicate that the engineer should consider more than one M&R alternative. Selecting the best alternative often requires performing an economic analysis to compare the cost effectiveness of all feasible alternatives. This section presents an economic analysis procedure which compares M&R alternatives based on present worth. The procedure for determining the present worth of each alternative consists of the steps shown in Figure 16. Following is a brief description of each of the steps:

1. Select an economic analysis period (in years). The period generally used in pavement analysis ranges from 10 to 30 years, depending on future use of the feature (abandonment, change of mission, etc.). Using the present-worth method of economic analysis, the analysis period should be the same for all alternatives.

2. Select interest and inflation rates to be used in calculating the present cost. This is a very important step since the selected rates have a significant impact on the ranking of the alternatives with respect to their present worth. The effect of interest rate (assuming constant inflation rate) on the ranking of M&R alternatives is illustrated in Figure 17. Detailed background information for Figure 17 is provided in Section VII. From the figure, it can be noted that as the interest rate increases, alternatives with higher initial cost become less attractive (based on cost) when compared to alternatives with higher future costs (such as localized repair as needed). The selection of the rates, therefore, should be based on Air Force policies and guidelines. It should be indicated, however, that the inflation rate used to compute present worth is the differential inflation rate, i.e., the rate of cost increase above the general inflation rate. Therefore, if the cost increase of a specific item is in line with the cost growth experienced by the economy, the differential inflation rate is assumed to be zero.

3. Estimate the annual cost for each M&R alternative for every year work is planned during the analysis period. These estimates should be based on current prices.

4. Determine the salvage value (SV) of an M&R alternative as follows:

$$SV = B - R \qquad \text{[Equation 3]}$$

where B = cost of building a new pavement on top of the subgrade; this cost should be kept the same for all M&R alternatives

R = cost of rehabilitation at the end of the analysis period for the M&R alternative under consideration so that the pavement will be equivalent to a new pavement (all costs should be determined based on current prices)

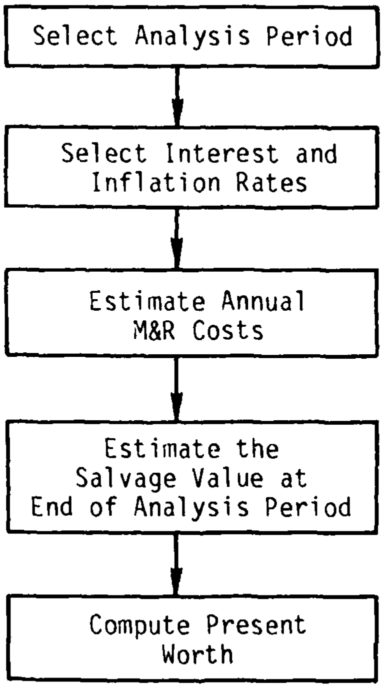


Figure 16. Steps for Determining Present Worth for Each M&R Alternative.

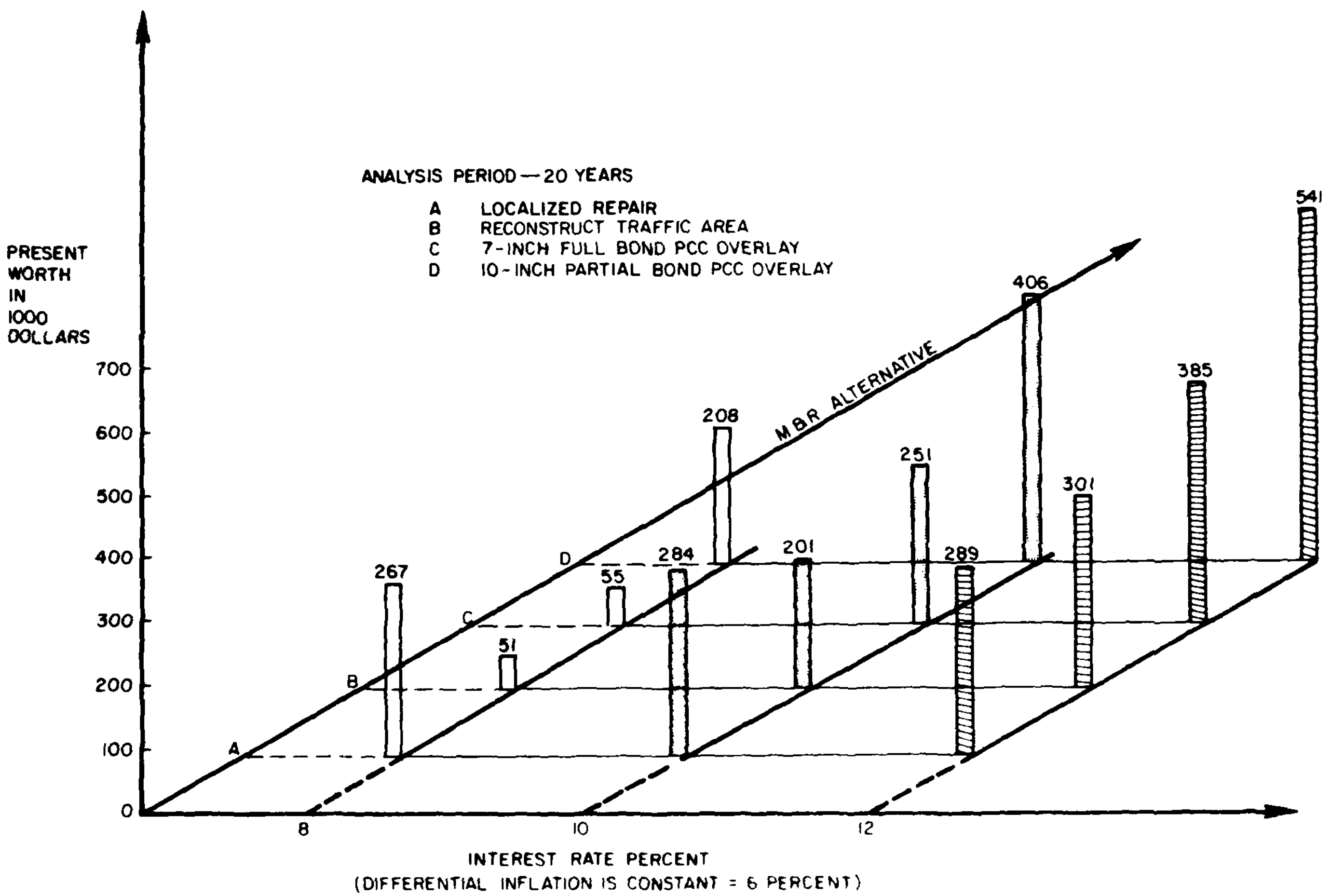


Figure 17. Effect of Interest Rate on M&R Alternative.

The salvage value as defined here is the relative value of the selected alternative at the end of the analysis period (which may be a negative value if it is badly deteriorated).

5. Compute the present worth for each M&R alternative as follows:

$$\text{Present worth} = [\sum_{i=1}^{n} C_i \times f_i] - SV \times f_n \qquad \text{[Equation 4]}$$

where n = number of years in the analysis period

C_i = M&R cost for year i calculated based on current prices

f_i = present worth factor for i^{th} year that is function of the interest rate (r_t), and inflation rate (r_f); $f_i = \left(\frac{1 + r_f}{1 + r_t}\right)^i$

f_n = present worth factor at the end of analysis period.

By substituting Equation 3 into Equation 4, Equation 4 becomes

$$\text{Present worth} = [\sum_{i=1}^{n} C_i \times f_i] - (B-R) \times f_n \qquad \text{[Equation 5]}$$

Since the value of B is the same for all M&R alternatives, its value may be assumed to be zero for comparative purpose. Thus, Equation 5 becomes:

$$\text{Present worth} = [\sum_{i=1}^{n} C_i \times f_i] + R \times f_n \qquad \text{[Equation 6]}$$

The physical interpretation of Equation 6 is that the present worth of any M&R alternative is the sum of all the discounted M&R costs during the analysis period plus the cost of rehabilitating the pavement at the end of the analysis period (so that it will be equivalent to a new pavement) as discounted to the present. The use of either Equation 5 or 6 in computing the present worth of each M&R alternative will not change the ranking of the various M&R alternatives.

After completion of these basic steps, comparing the present worth for all M&R alternatives will help the pavement engineer select the most economical repair alternative. Figure 18 illustrates a format designed to simplify use of the procedure for computing the present worth of each M&R alternative.

A number of predictions and assumptions must be made in order to perform the economic analysis. The engineer must therefore use judgment in selecting the best inputs.

Efforts are currently under way to develop models for predicting the consequences of applying various M&R alternatives. These would include models for predicting PCI and key distress types as the function of pavement structure, traffic, environment, material properties, and M&R method. When completed, these models will provide valuable input to the economic analysis procedure.

M & R ALTERNATIVE ______________________________

____

ANALYSIS PERIOD ________ YEARS INTEREST RATE ______ %

INFLATION RATE ______ %

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
			TOTAL	$

SALVAGE VALUE = = $ ______________________________

PRESENT WORTH = $ ______________________________

Figure 18. Calculation Sheet for Determining Present Worth of an M&R Alternative.

SECTION VI

EXAMPLE APPLICATION OF M&R GUIDELINES -- ASPHALT RUNWAY FIELD CASE

This section provides an example application of the overall procedure for determining optimum M&R requirements. The steps of the application are data collection, condition evaluation, selection of feasible M&R alternatives, economic analysis, and selection of the optimum M&R alternative.

The pavement used in this example is the asphaltic concrete (AC) portion of a runway located in North Carolina. Figure 19 shows the airfield layout plan. The runway (R/W 5/23) is the airfield's only runway and is 7500 feet long and 150 feet wide. The first 1000 feet from threshold 23 are constructed with 17-inch PCC slabs, and the first 300 feet from threshold 5 are constructed with 12-inch PCC slabs. The rest of the runway is surfaced with AC and is made up of variable pavement structures (Figure 20). The primary aircrafts using the runway are the C-130 and C-141. The pavement is exhibiting distress, and the engineer is concerned about the current pavement deterioration and the amount of maintenance required to correct it.

A pavement condition survey was performed on the runway in December 1977. Prior to this survey, it had been observed that the concrete ends of the runway were in very good condition and that most distress in the AC surface occurred within the central 75 feet. A condition survey of a few sample units located at the outside of the runway showed that the condition rating was excellent. Therefore, only the central 75 feet were considered when determining M&R requirements. Figure 20 shows the PCI values for the individual sample units and features surveyed, and these features' construction history. Feature R6C was divided into two features -- R6C(A) and R6C(B) -- because of a large difference in PCI. R6C(A) had a PCI of 51, while R6C(B) had a PCI of 81. Pavement cores taken from the feature by the AFESC showed that the surface thickness for R6C(B) was 7.5 inches, but was only 5 inches for R6C(A).

DATA COLLECTION

Sample units were alternately surveyed and skipped throughout the entire length of the central 75 feet of the AC runway portion. Each sample unit was 50 feet long. Figure 20 is a plot of the PCI along the runway. Table 6 summarizes the estimated distress found in each pavement feature (extrapolated based on the number of sample units surveyed) and the corresponding deduct values. Figures 21 through 25 are representative photographs of different pavement features in the runway.

CONDITION EVALUATION

Table 7 provides a breakdown of the distress types and percent deduct values in terms of load and climate. An overall evaluation was performed for each feature to select feasible M&R alternatives. Figures 26 and 27 show the

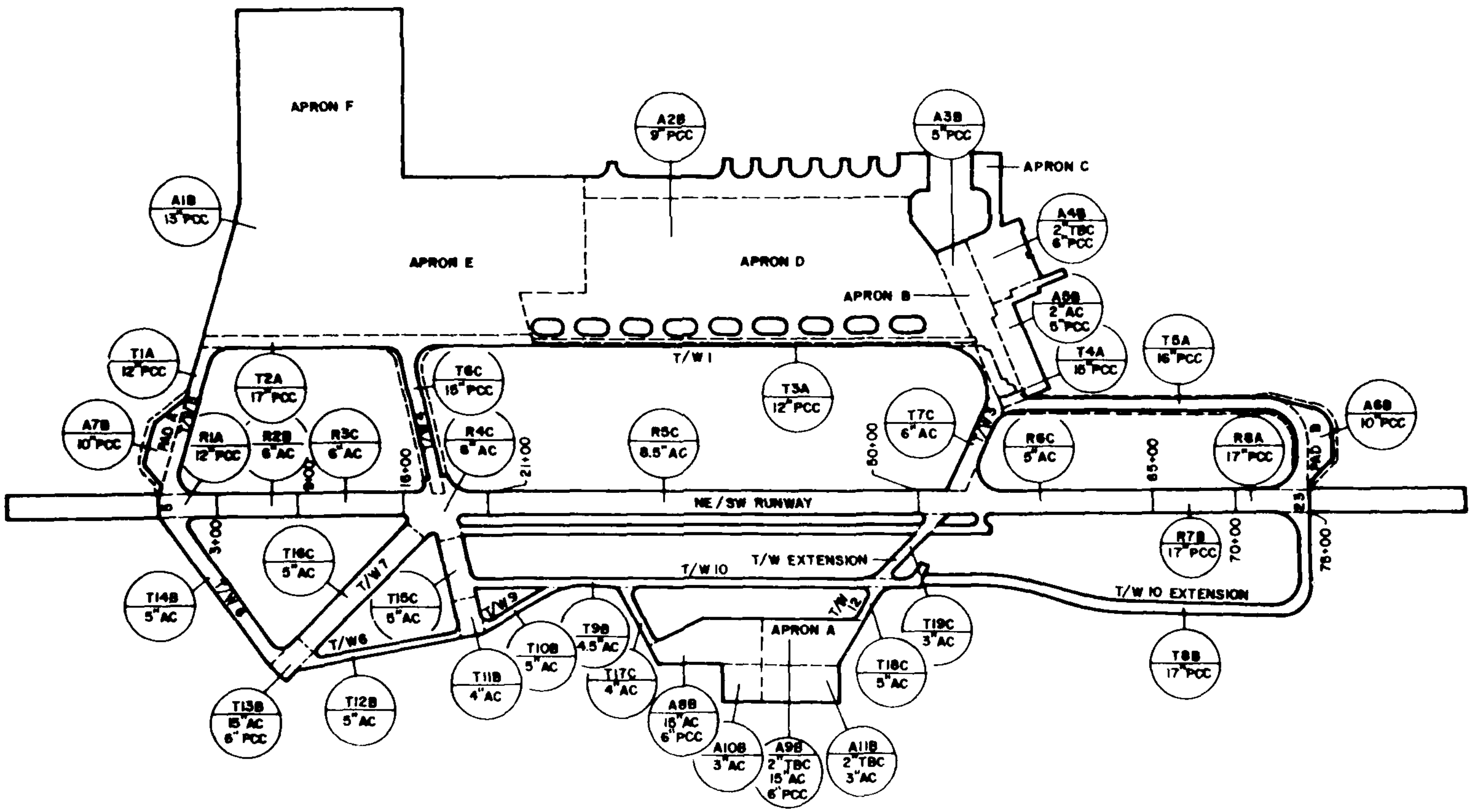


Figure 19. Airfield Layout Plan.

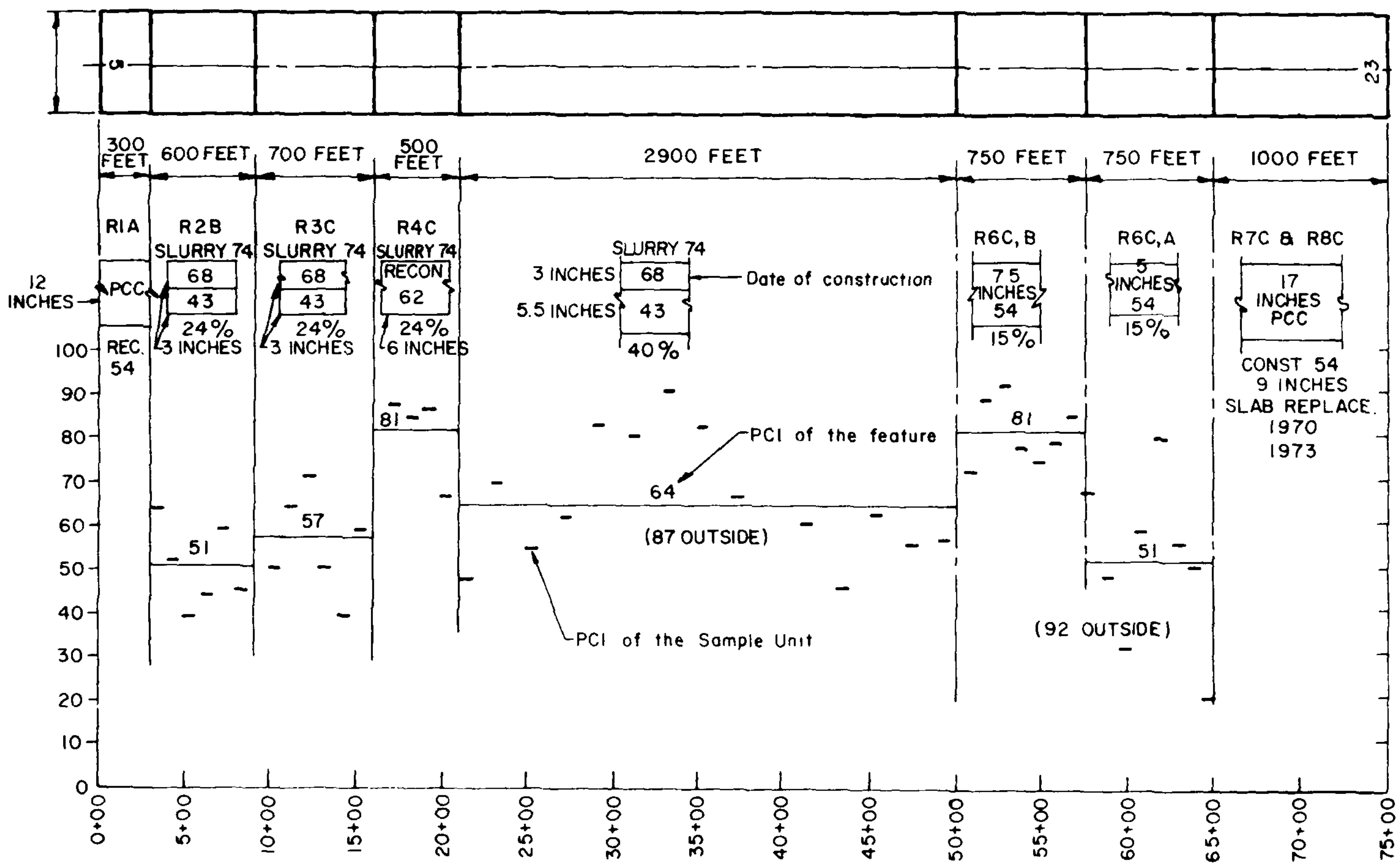


Figure 20. Construction History of Entire Runway and PCI Profile for Central 75 Feet.

TABLE 6. DISTRESS DATA FOR INDIVIDUAL FEATURES

Estimated Distress for Feature: R2B-Center 75 Feet Pope AFB

Distress-Type	Severity	Quantity	Density (%)	Deduct Value
Alligator Cracking	Low	2762	6.13	38.1
Alligator Cracking	Medium	2014	4.47	45.4
Block Cracking	Low	1352	3.00	11.2
Joint Reflection Crk	Low	150	0.33	0.1
Joint Reflection Crk	Medium	72	0.16	0.6
Long/Transv Crk	Low	656	1.45	6.4
Long/Transv Crk	Medium	454	1.00	11.5

Estimated Distress for Feature: R3C-Center 75 Feet Pope AFB

Distress-Type	Severity	Quantity	Density (%)	Deduct Value
Alligator Cracking	Low	320	0.60	15.7
Alligator Cracking	Medium	468	0.89	28.2
Alligator Cracking	High	80	0.15	19.5
Block Cracking	Low	2800	5.33	14.1
Block Cracking	Medium	1700	3.23	16.4
Long/Transv Crk	Low	760	1.44	6.3
Long/Transv Crk	Medium	950	1.80	15.4
Long/Transv Crk	High	50	0.09	6.7
Rutting	Low	180	0.34	11.4
Rutting	Medium	400	0.76	22.3

Estimated Distress for Feature: R4C-Center 75 Feet Pope AFB

Distress-Type	Severity	Quantity	Density (%)	Deduct Value
Alligator Cracking	Low	424	1.13	21.5
Block Cracking	Low	320	0.85	7.4
Long/Transv Crk	Low	376	1.00	5.5
Long/Transv Crk	Medium	238	0.63	8.9

Estimated Distress for Feature: R5C-Center 75 Feet Pope AFB

Distress-Type	Severity	Quantity	Density (%)	Deduct Value
Alligator Cracking	Low	6476	2.97	31.3
Alligator Cracking	Medium	2323	1.06	30.0
Block Cracking	Low	4833	2.22	10.1
Block Cracking	Medium	4640	2.13	14.5
Long/Transv Crk	Low	2691	1.23	5.9
Long/Transv Crk	Medium	4176	1.92	15.9
Long/Transv Crk	High	348	0.16	8.7
Patching	Low	46	0.02	0.4

TABLE 6. DISTRESS DATA FOR INDIVIDUAL FEATURES (CONCLUDED)

Estimated Distress for Feature: R6C-Center 75B Pope AFB

Distress-Type	Severity	Quantity	Density (%)	Deduct Value
Alligator Cracking	Low	205	0.36	11.8
	Medium	17	0.03	3.0
Block Cracking	Low	540	0.96	7.7
Long/Transv Crk	Low	593	1.05	5.6
	Medium	756	1.34	13.3
Rutting	Low	321	0.57	13.0

Estimated Distress for Feature: R6C-Center 75A Pope AFB

Distress-Type	Severity	Quantity	Density (%)	Deduct Value
Alligator Cracking	Low	1698	3.01	31.5
	Medium	2587	4.59	45.7
Block Cracking	Low	2283	4.05	12.5
	Medium	476	0.84	11.1
Long/Transv Crk	Low	1260	2.24	8.4
	Medium	213	0.37	6.7
Patching	Low	277	0.49	2.4
Rutting	Low	1166	2.07	18.8
	Medium	573	1.01	24.0

igure 21. Feature R6C(A) -- Medium-Severity Alligator Cracking.

Figure 22. Feature R6C(B) -- Some Low-Severity Longitudinal Cracking.

Figure 23. Feature R4C -- Low-Severity Longitudinal and Transverse Cracking.

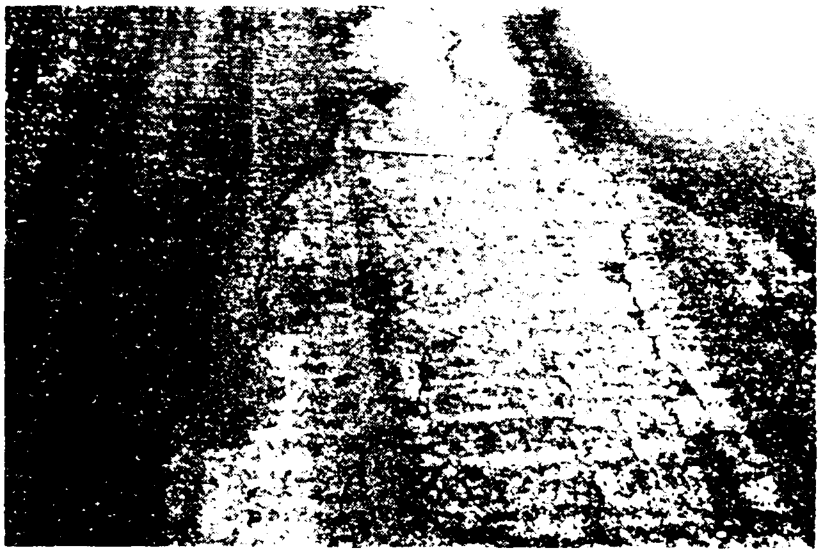


Figure 24. Feature R3C -- Medium-Severity Alligator Cracking.

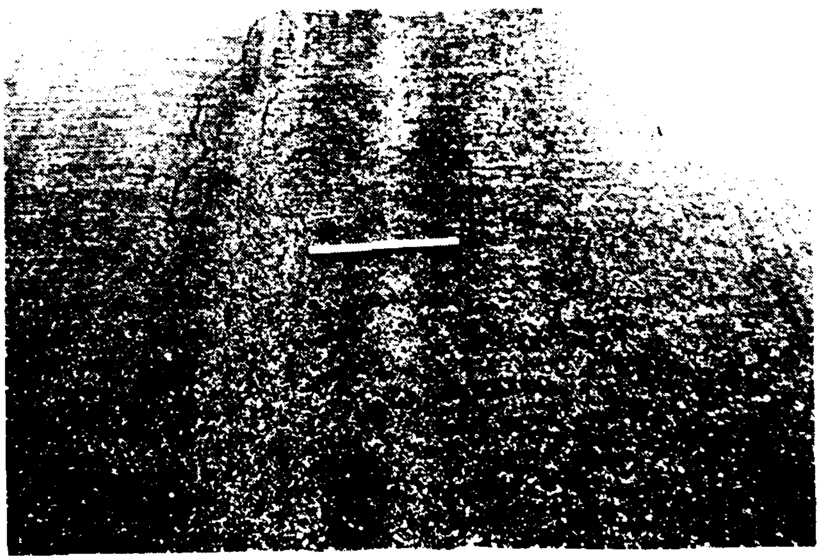


Figure 25. Feature R2B -- Medium Severity Alligator Cracking.

TABLE 7. SUMMARY OF DISTRESS EVALUATION

Load-Associated Distress			Climate/Durability Associated Distress	
Feature	Type	Deduct Value (%)	Type	Deduct Value (%)
R2B	Alligator Cracking	74	Block Cracking, Joint Reflection, L&T Cracking	26
R3C	Alligator Cracking, Rutting	62 62	Block Cracking, L&T Cracking	38
R4C	Alligator Cracking	50	Block Cracking L&T Cracking	50
R5C	Alligator Cracking, Patching	53	Block Cracking L&T Cracking	47
R6C(A)	Alligator Cracking, Patching, Rutting	76	Block Cracking L&T Cracking	24
R6C(B)	Alligator Cracking, Rutting	51	Block Cracking, L&T Cracking	49

Facility: Runway 5/23 Feature: R2B

1. Overall Condition Rating - PCI =51

Excellent, Very Good, Good, Fair, Poor, Very Poor, Failed.

2. Variation of Condition Within Feature - PCI

   a. Localized Random Variation — Yes, No
   b. Systematic Variation: — Yes, No

3. Rate of Deterioration of Condition - PCI

   a. Long-term period (since construction) overlaid 1968 — Low, Normal, High
   b. Short-term period (1 year) unknown — ~~Low, Normal, High~~

4. Distress Evaluation

   a. Cause

Load Associated Distress	74	percent deduct values
Climate/Durability Associated	26	percent deduct values
Other (___) Associated Distress	0	percent deduct values

   b. Moisture (Drainage) Effect on Distress — Minor, Moderate, Major

5. Load-Carrying Capacity Deficiency — No, Yes

6. Surface Roughness No info available — ~~Minor, Moderate, Major~~

7. Skid Resistance/Hydroplaning (runways only) — No hydroplaning problems are expected

   a. Mu-Meter — Transitional; Potential for hydroplaning; Very high probability

   b. Stopping Distance Ratio — No hydroplaning anticipated; Potential not well defined; Potential for hydroplaning; Very high hydroplaning potential

   c. Transverse Slope — Poor, Fair, Good, Excellent

8. Previous Maintenance — Low, Normal, High

9. Effect on Mission (Comments): (a) Long-time closure of runway will require mission relocation. (b) It is better to plan short-time closures than to be forced to close due to severe deterioration

Figure 26. R2B Pavement Condition Evaluation Summary.

Facility: Runway 5/23 Feature R5C

1. Overall Condition Rating - PCI = 64

Excellent, Very Good, Good, Fair, Poor, Very Poor, Failed.

2. Variation of Condition Within Feature - PCI

a. Localized Random Variation — Yes, No
b. Systematic Variation: — Yes, No

3. Rate of Deterioration of Condition - PCI

a. Long-term period (since construction) Overlaid 1968 — Low, Normal, High
b. Short-term period (1 year) Unknown — ~~Low, Normal, High~~

4. Distress Evaluation

a. Cause

Load Associated Distress	53	percent deduct values
Climate/Durability Associated	47	percent deduct values
Other (___) Associated Distress	0	percent deduct values

b. Moisture (Drainage) Effect on Distress — Minor, Moderate, Major

5. Load-Carrying Capacity Deficiency — No, Yes

6. Surface Roughness No info available — ~~Minor, Moderate, Major~~

7. Skid Resistance/Hydroplaning (runways only) — No hydroplaning problems are expected

a. Mu-Meter — Transitional / Potential for hydroplaning / Very high probability

b. Stopping Distance Ratio — No hydroplaning anticipated / Potential not well defined / Potential for hydroplaning / Very high hydroplaning potential

c. Transverse Slope — Poor, Fair, Good, Excellent

8. Previous Maintenance — Low, Normal, High

9. Effect on Mission (Comments): (a) Long-time closure of runway will require mission relocation (b) It is better to plan short-time closures than to be forced to close due to severe deterioration

Figure 27. R5C Pavement Condition Evaluation Summary.

evaluation results for features R2B and R5C, respectively. Appendix A summarizes the evaluation for the rest of the runway features.

Feature R2B (Figure 26) has a PCI of 51 and therefore a "fair" rating. No localized or systematic variation was observed. The long-term rate of deterioration was determined from Figure 8 to be normal, based on a PCI of 51 after 10 years since overlay. The load-associated distress caused 74 percent of the total deduct value. Also, using Airfield Pavement Evaluation Curves (Figure 28), the load-carrying capacity was determined to be deficient for C-141 aircraft. The estimated number of aircraft passes to failure was 50, and the pavement had already been subjected to much more than that.

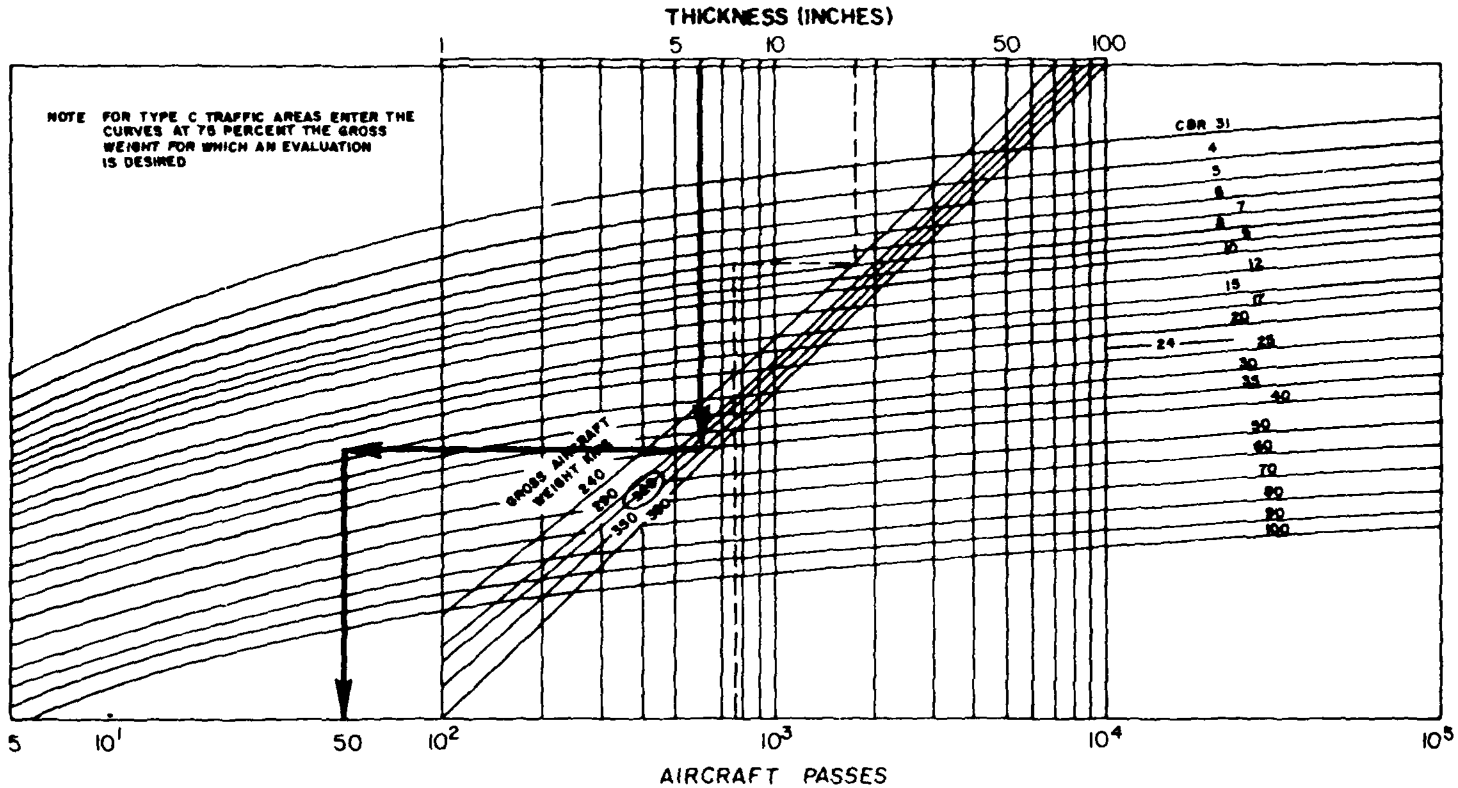
Based on a PCI of 51, the feature is placed in the R-M-O zone. The M&R guidelines for this zone state that routine or major M&R should generally be applied and that overall M&R should be considered if one or more of the condition indicators is exceeded. Several of these indicators were exceeded for feature R2B.

A similar evaluation was performed for feature R5C (Figure 27). It should be noted that the load-carrying capacity (Figure 29) was not determined to be deficient (item 5, Figure 27); however, load-associated distress caused 53 percent of the total deduct value (item 4a). In addition, it should be noted that there is localized random variation (item 2a). The lowest sample unit PCI value for the feature is 42, which is lower than the sample unit critical minimum PCI value of 48 determined from Figure 4 for a mean PCI of 54.

FEASIBLE M&R ALTERNATIVES AND ECONOMIC ANALYSIS FOR INDIVIDUAL FEATURES

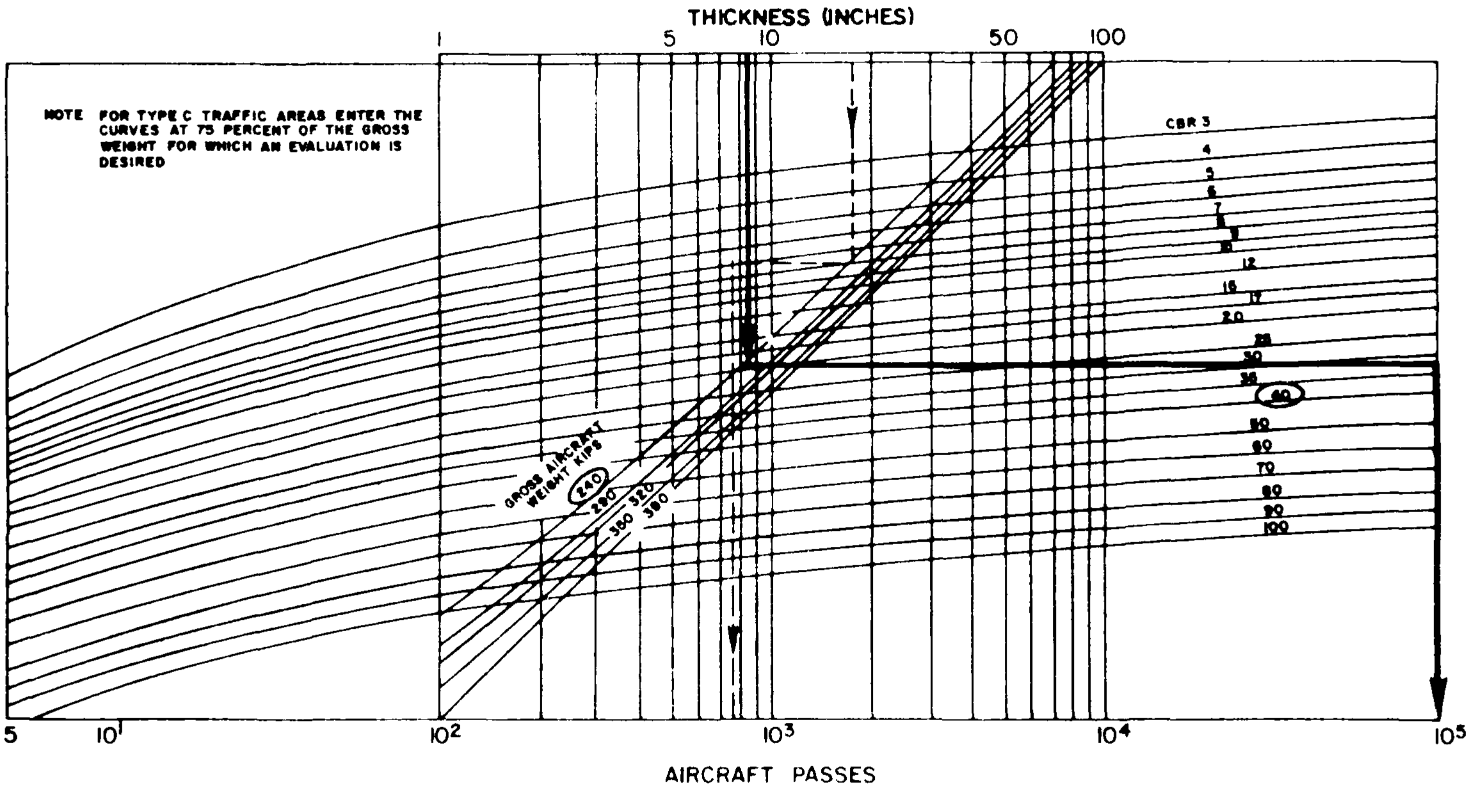
Based on the evaluation results, several alternatives were considered for each feature and economic analysis performed. Figures 30 and 31 show the alternatives and associated costs for features R2B and R5C, respectively. The costs in the figures are shown in terms of the discounted present cost (PC), the salvage value (SV), and the present worth (PW). The PW is determined by subtracting the SV from the PC as shown in Equation 4. The economic analysis for each alternative was based on current local costs where the airfield is located (Table 8). Table 9 provides the detailed economic analysis for alternative 2, feature R2B. The main difficulties in performing the economic analysis were predicting future localized repair and estimating the SV at the end of the analysis period. These difficulties should be greatly decreased or eliminated when the development of models for predicting PCI and key distress is completed (Reference 9). For the analysis of this alternative, routine localized maintenance was assumed to be $0.1 per square yard 5 years after construction; it was increased by $0.1 per square yard every additional 5 years. This assumption was based primarily on current average maintenance costs and engineering judgment. Similar assumptions were made when analyzing the other alternatives. The SV was determined as follows:

1. Cost of constructing a new pavement over a subgrade (design was based on U.S. Army Corps of Engineers criteria):



FLEXIBLE PAVEMENT EVALUATION CURVES, C-141, TYPE B AND C TRAFFIC AREAS

Figure 28. Load-Carrying Capacity Evaluation for Feature P2B.



FLEXIBLE PAVEMENT EVALUATION CURVES, C-141, TYPE B AND C TRAFFIC AREAS

Figure 29. Load-Carrying Capacity Evaluation for Feature R5C.

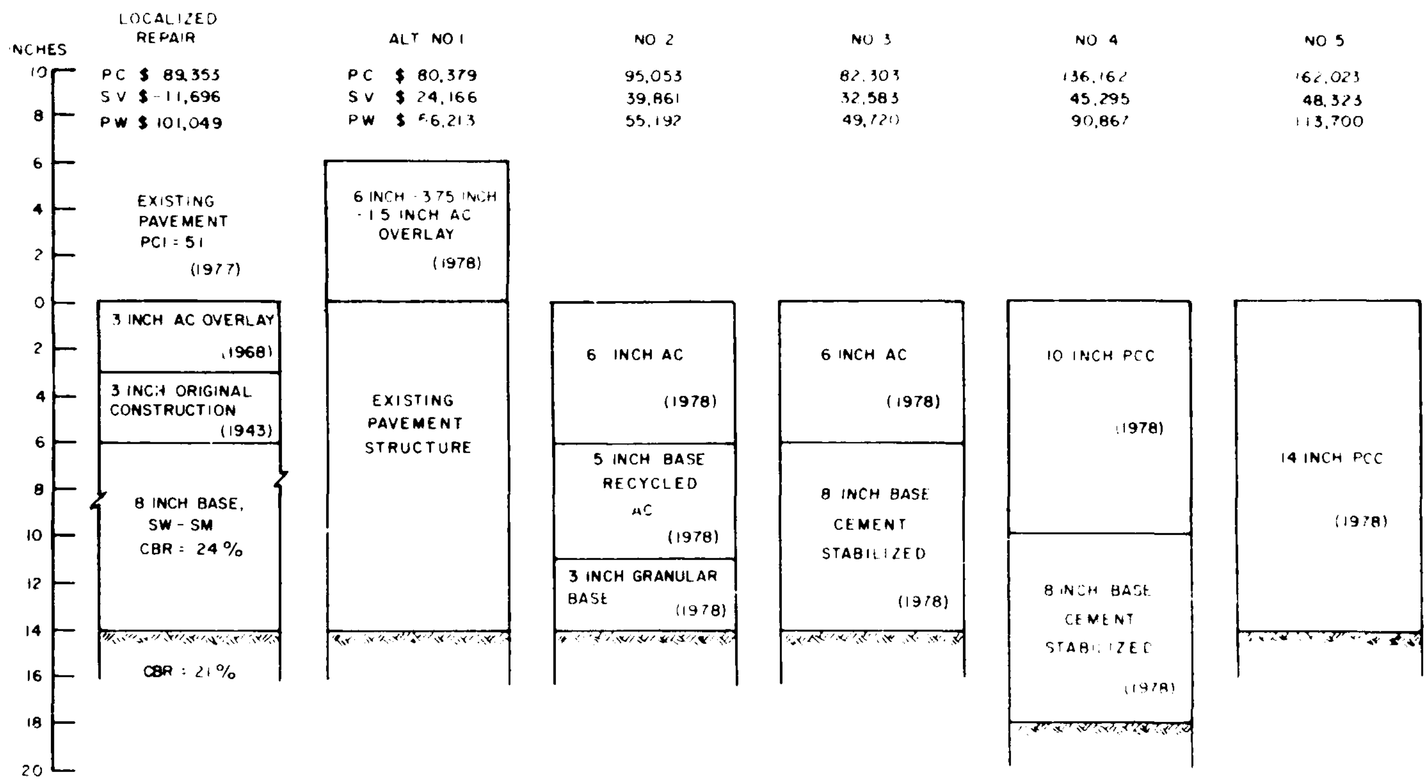
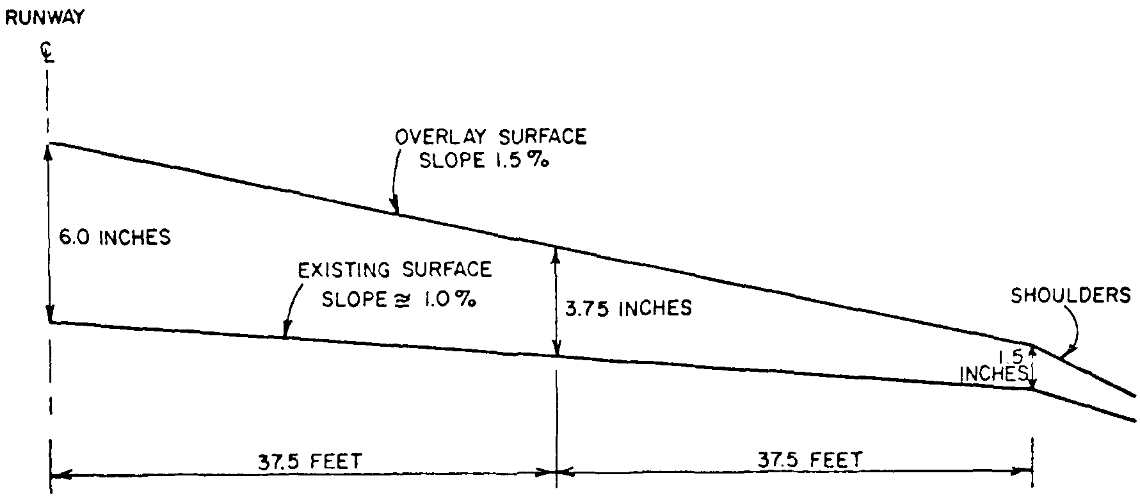


Figure 30. Repair Alternatives for Feature R2B.

Alternative 1:

Overlay the entire feature with AC. The cross-section of the overlay will be as shown below. Localized repair, e.g., full-depth patching, must be performed before overlaying.



Alternative 2:

Remove base course and recycle AC surface keel section. Place a 3-inch granular material on top of the existing subgrade. Use recycled AC surface of approximately 5 inches as a stabilized base course. Add 6 inches of AC surface course.

Alternative 3:

Remove the existing AC surface keel section, and replace it with a 6-inch AC after stabilizing the 8-inch base with cement (in place).

Alternative 4:

Replace the 6-inch AC keel section with 10-inch PCC slabs after removing 4 inches of base course and stabilizing the remaining 4 inches plus 4 inches of subgrade material.

Alternative 5:

Reconstruct the keel section with 14-inch PCC slabs after removing the AC surface and the base.

Figure 30. Repair Alternatives for Feature R2B (Concluded).

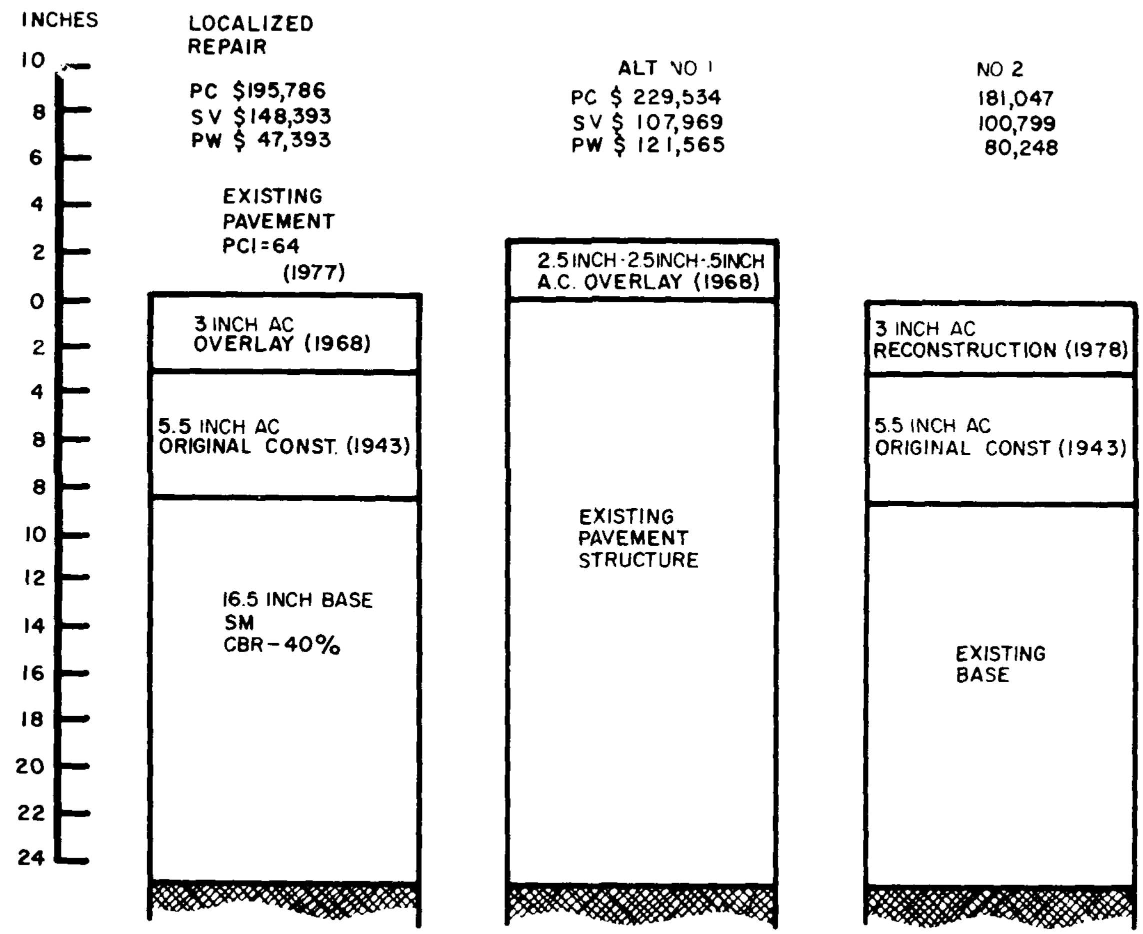
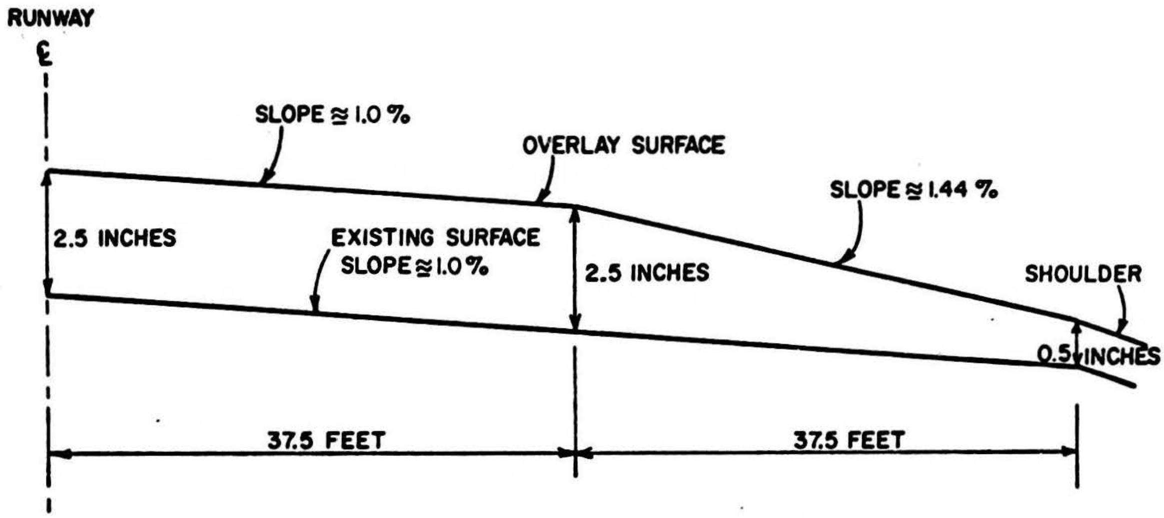


Figure 31. Repair Alternatives for Feature R5C.

Alternative 1:

Overlay the entire feature with AC. Localized repair must be performed before overlaying. The cross-section of the overlay is shown below.



Alternative 2:

Remove 3 inches from the AC surface, and add a new 3-inch AC surface layer.

Alternative 3:

Perform localized repair as needed over the next 10 years. In 1988, scarify 3 inches from the AC surface keel section, and add a new 3-inch AC surface.

Figure 31. Repair Alternatives for Feature R5C (Concluded).

TABLE 8. UNIT COST OF REPAIR, SEPTEMBER 1978

Remove AC Surface and Dispose of It	$00.30/Square Yard/Inch
Scarify AC Surface and Dispose of It	00.50/Square Yard/Inch
Remove AC Surface with Rotomill and Windrow	00.50/Square Yard/Inch
Place AC	30.00/Ton
Place Tack Coat or Prime (0.10 Gallons/Square Yard)	00.05/Square Yard
Place PCC	65.00/Cubic Yard
Remove Base Material and Dispose of It	00.20/Square Yard/Inch
Place Granular Material	15.00/Cubic Yard
Compact Granular Material	00.50/Square Yard
Place Recycled AC as Base Source from Windrow and Compaction and Sweetening and Prime Coat	00.25/Square Yard/Inch
Place Cement Stabilization	00.45/Square Yard/Inch
Prepare Subgrade After Removal of Base Course	00.75/Square Yard
R/W or T/W Marking Paint	01.75/Square Yard
Deep Patch	01.75/Square Yard/Inch AC
Crack Seal	00.45/Foot
Joint Seal	00.70/Foot
Slurry Seal	00.50/Square Yard
Apply Rejuvenator	00.27/Square Yard

TABLE 9. ECONOMIC ANALYSIS FOR ALTERNATIVE 2, FEATURE R2B

M & R ALTERNATIVE #2 Feature R2B Reconstruct Central 75-Feet (Keel-Section) with 6" AC on Asphalt Stabilized Base (Recycled)

ANALYSIS PERIOD ______ **YEARS** **INTEREST RATE** ______ **%**

INFLATION RATE ______ **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1978	Remove AC Surface, Keel-Section			
	with Rotomill and Windrow @			
	$0.50/SY/IN	15,000	1.0	15,000
1978	Remove the 8-in. Base Course			
	and Dispose of it @$0.20/SY/IN	8,000	1.0	8,000
1978	Place 3-in Granular Base			
	Material @ $15.00/CY	6,250	1.0	6,250
1978	Compaction of Granular Base			
	@ $0.50/SY	2,500	1.0	2,500
1978	Place a Prime Coat on Top of			
	Granular Base @ $0.15/.3Gal/SY	750	1.0	750
1978	Place the Recycled AC Surface			
	(≈5") As A Base in Two Lifts @			
	$0.35/SY/IN	7,500	1.0	7,500
1978	Place 6-in AC Surface @ $30.00/Ton	48,938	1.0	48,938
1978	Marking (15% area) @ $1.75/SY	2,625	1.0	2,625
1983	Routine M&R @ $0.10/SY	500	.911	456
1988	Routine M&R @ $0.20/SY	1,000	.830	830
1993	Routine M&R @ $0.30/SY	1,500	.755	1,133
1996	Routine M&R @ $0.30/SY	1,500	.714	1,071
			TOTAL	$95,053

SALVAGE VALUE = 57,938 x 0.688 = **$** 39,861

PRESENT WORTH = $ 55,192

Compact subgrade = $\frac{600 \text{ feet} \times 75 \text{ feet}}{9} \times 0.5$ = \$2,500

Place 6-inch granular base = $\frac{600 \times 75 \times 0.5}{27} \times 15$ = \$12,500

Compact base = \$2,500

Place prime coat (0.2 gallons per square yard) = $\frac{600 \times 75}{9} \times 0.1$ = \$500

Place 8-inch AC surface = $600 \times 75 \times \frac{8}{12} \times \frac{145}{2000} \times 30$ = \$62,250

Total = \$80,250

2. Cost of restoring the pavement (in alternative 2) after 20 years (based on current prices):

Scarify the top 2 inches of AC and dispose of it = $\frac{600 \times 75}{9} \times 0.5 \times 2$ = \$5,000

Routine M&R at \$0.2 per square yard = \$1,000

Place 2 inches AC = $600 \times 75 \times \frac{2}{12} \times \frac{145}{2000} \times \$30$ = \$16,312

TOTAL = \$22,312

3. Salvage value based on current costs = Cost of new construction - cost of restoration after 20 years
= 80,250 - \$22,312
= \$57,938

4. Present worth factor (f): after 20 years (see Equation 4):

Inflation rate = 6 percent

Interest rate = 8 percent

$$20 = \left(\frac{1 + 0.06}{1 + 0.08}\right)^{20}$$

$$= 0.688$$

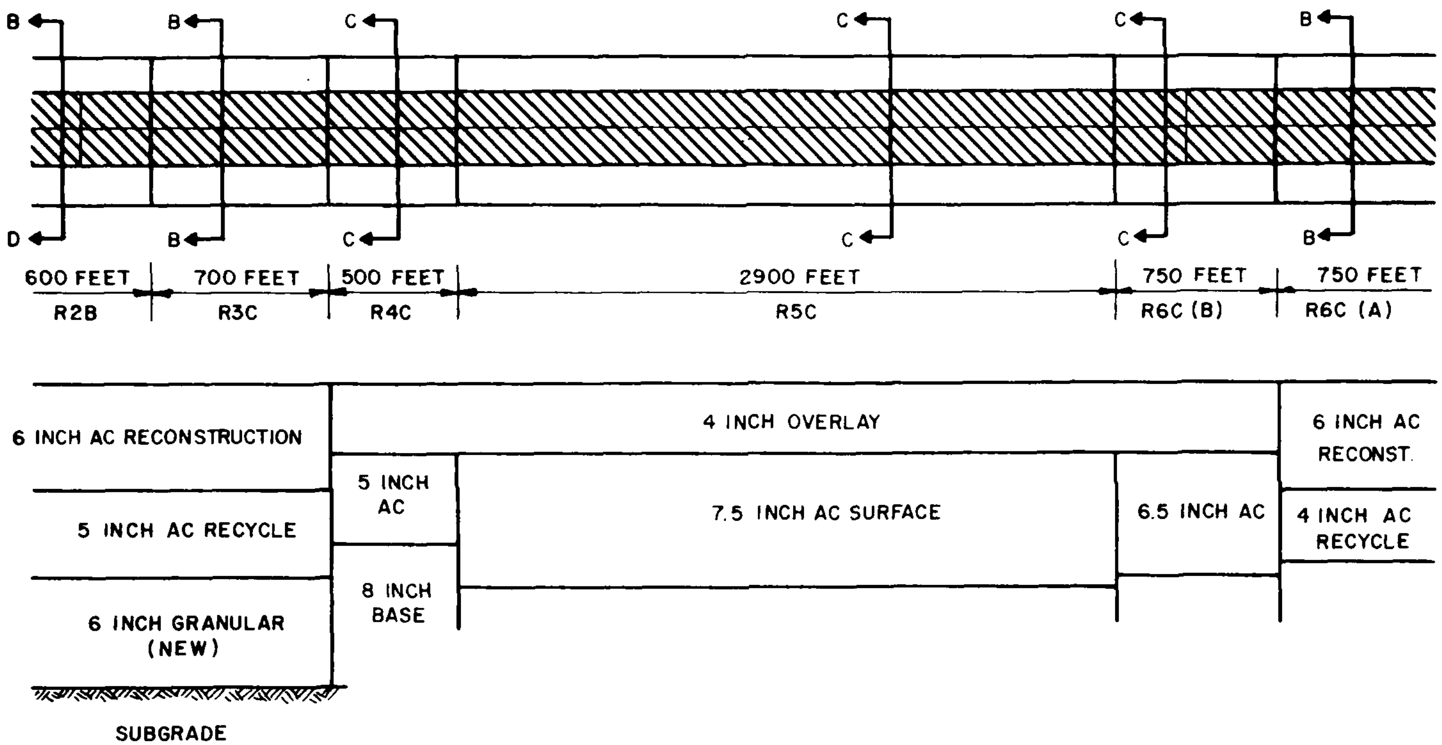
5. Discounted SV = \$57,938 x 0.688 = \$39,861

When calculating the SV for other alternatives, the cost of new construction remains the same. The only item that changes is the cost of restoration after the analysis period (20 years in this case). Appendix B presents the detailed economic analysis for all the alternatives considered for feature R2B. Appendix C presents the alternatives and associated costs for features other than R2B and R5C.

M&R ALTERNATIVES AND ECONOMIC ANALYSIS FOR THE ENTIRE RUNWAY

After the alternatives for the individual features were evaluated, six alternatives were analyzed for the runway. This process is important, because merely combining the most economical alternative for each feature may not provide the most economical alternative for the entire runway. This is partly due to (1) elimination of the need for overlay feathering because of the difference in elevation between features, (2) the variation of unit cost of repair based on volume of work, and (3) the facility's downtime. Figures 32 through 37 present the alternatives.

Table 10 provides a summary comparison of the costs for the six alternatives, and Appendix D provides the detailed computations from which this summary was derived. It should be emphasized that the most economical alternative is not necessarily the most desirable one because of the variety in airfield mission considerations and management policies; however, in this example, the most economical alternative (No. 6) was selected and is currently being implemented, with either minor or no modifications.



Alternative No 1:

a. For features R2B, R3C, and R6C (A) Remove base course and recycle AC surface (keel section). Place granular material on top of existing subgrade as needed for leveling. Use recycled AC surface as stabilized base course. Add 6 inches of AC surface course.

b. For features R4C, R5C, and R6C (B) Remove 1 inch of AC surface, and place 4 inches of AC as an overlay.

Figure 32. Considered Repair Alternative for Entire Runway -- Alternative 1.

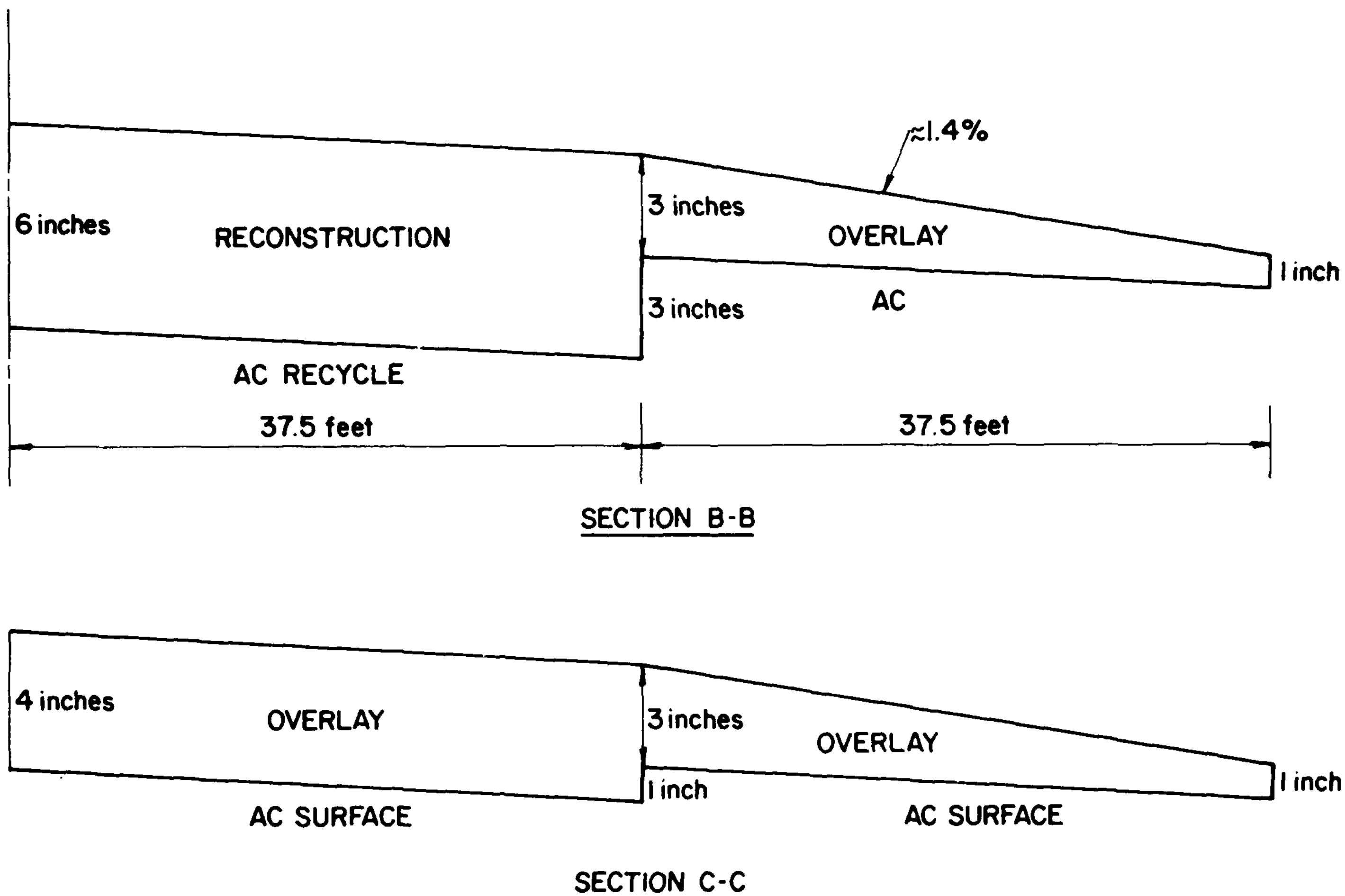
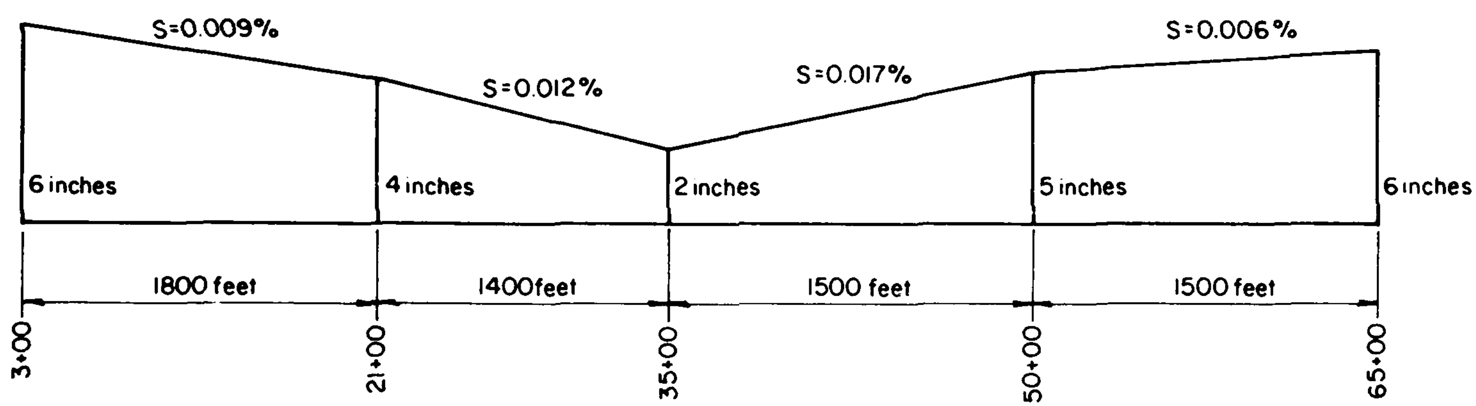


Figure 32. Considered Repair Alternatives for Entire Runway -- Alternative 1 (Concluded).

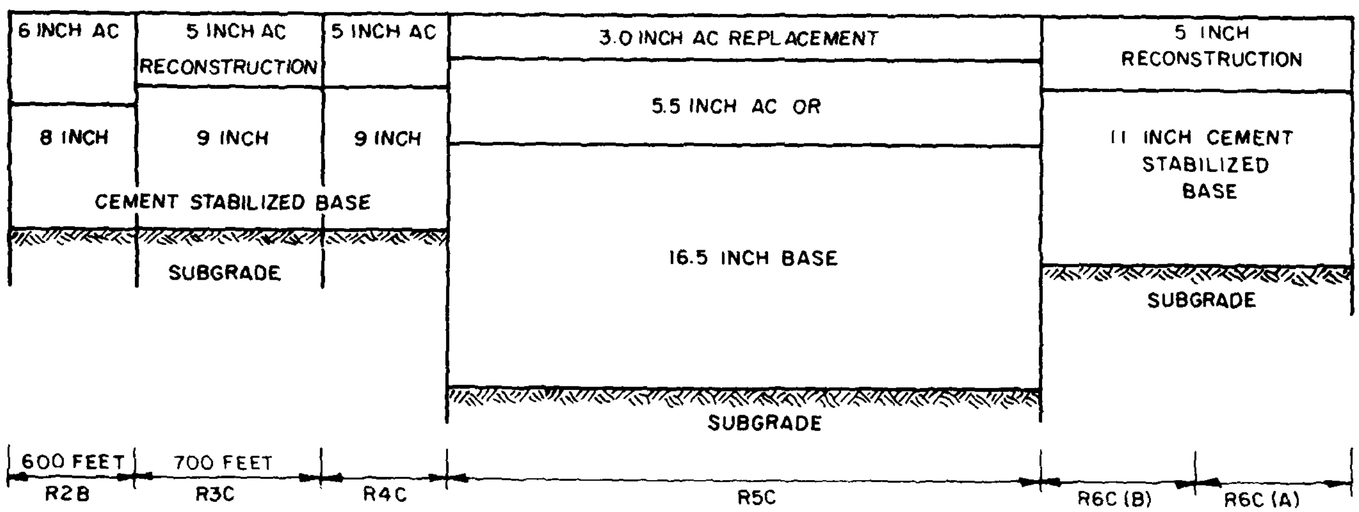


PC $ 727,959
SV $ 214,329
PW $ 513,630

Alternate No. 2
Overlay the entire length with AC after performing localized repair.

Figure 33. Considered Repair Alternatives for Entire Runway -- Alternative 2.

TOTAL COST: $629,269
SALVAGE VALUE: $238,790
PRESENT WORTH: $390,479



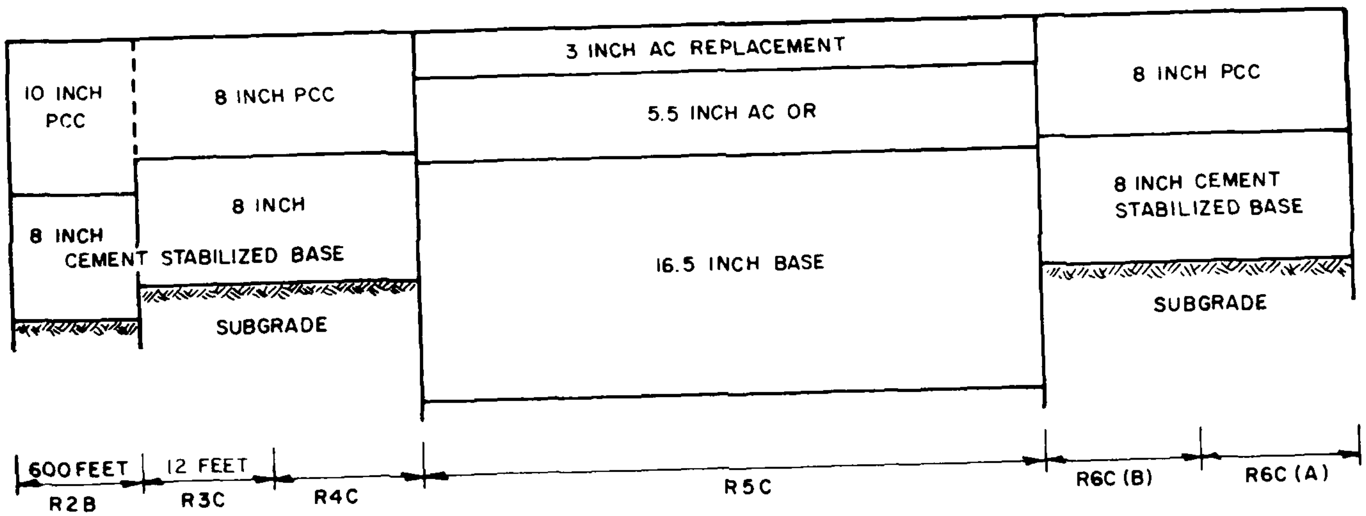
Alternative No. 3:

a. Remove the AC surface and stabilize the base course with cement after leveling the bases as needed. Place 6 inches of AC surface course, keel section, for feature R2B, and 5 inches of AC surface course, keel section, for features R3C, R4C, R6C(A), and R6C(B).

b. For feature R5C, remove 3 inches of AC surface, and add 3 inches of AC surface course, keel section.

Figure 34. Runway 5/23 -- M&R Alternative 3.

TOTAL COST $866,589
SALVAGE VALUE $308,384
PRESENT WORTH $558,205



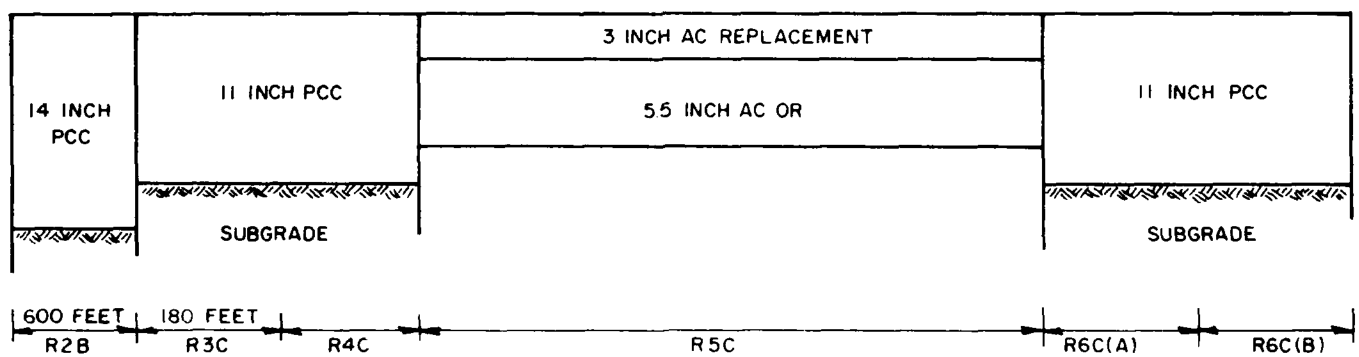
Alternative No. 4

a Remove the AC surface and part of the base courses for leveling as needed for features R2B, R3C, R4C, R6C(A) and R6C(B) (keel sections). Cement-stabilize the base courses, and place 10-inch PCC slabs on R2B, and 8-inch PCC slabs on other features.

b Remove 3 inches of AC surface, keel section, of feature R5C. Add 3 inches of AC surface course

Figure 35. Runway 5/23 -- M&R Alternative 4.

TOTAL COST $944,700
SALVAGE VALUE $327,924
PRESENT WORTH $616,776

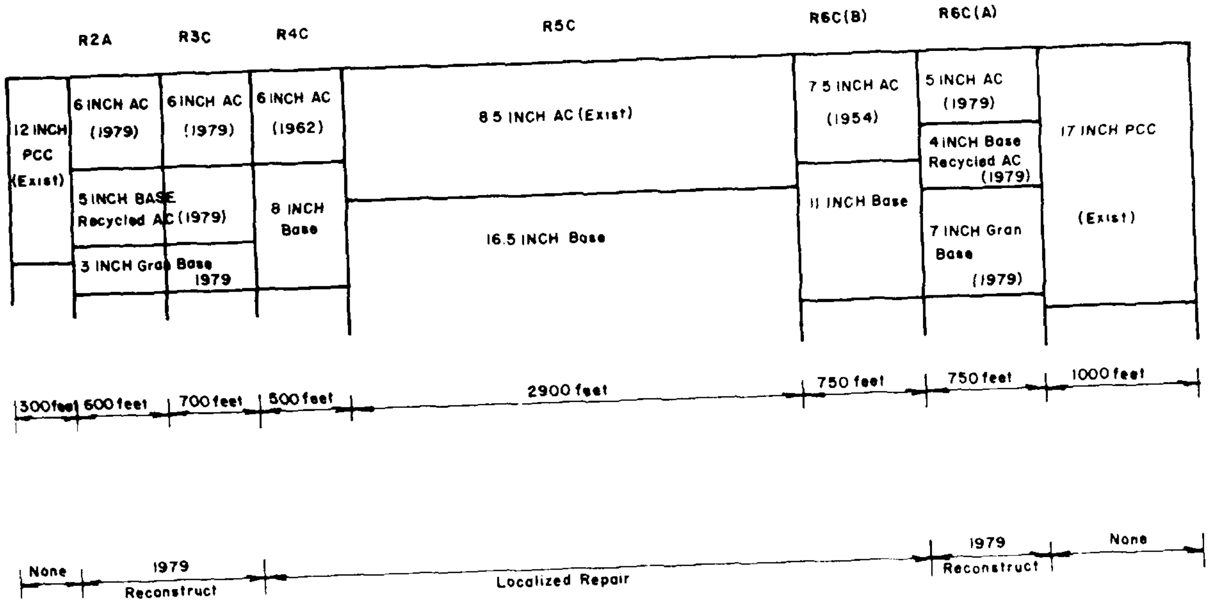


Alternative No 5

a Remove the AC surface and base courses for leveling, as needed, for features R2B, R3C, R4C(A), and R6C(B) (keel sections). Place 14-inch PCC slabs on R2B, and 11-inch PCC slabs on other features.

b Remove 3 inches from the AC surface, keel section, of feature R5C. Add 3-inch AC surface course.

Figure 36. Runway 5/23 -- M&R Alternative 5.



Alternative No. 6:

a. Perform localized repair as needed for 10 years on features R4C, R5C, and R6C (B).

b. In 1979, remove base course and recycle AC surface, keel section, of feature R6C (A). Place granular material on top of existing subgrade as needed for leveling. Place the recycled AC surface as stabilized base, and place the AC surface course.

c. In 1979, repeat item (b) for features R2A and R3C

d. In 1988, repeat item (b) for features R4C and R6C (B)

e. In 1988, scarify 3 inches of AC surface, keel section, of feature R5C, and then provide a new 3-inch AC surface.

Figure 37. Repair Alternatives for Entire Runway -- Alternative 6.

TABLE 10. SUMMARY COMPARISON OF M&R ALTERNATIVES
(ALL COSTS ARE TO THE NEAREST $1000)

Alternative	Total Discounted Present Cost (PC)	Salvage Value (SV)	Present Worth (PW)	Ratio to Most Economical Alternative
1	$758	$259	$499	1.36
2	$728	$214	$514	1.40
3	$629	$239	$390	1.06
4	$867	$308	$559	1.52
5	$945	$328	$617	1.68
6	$694	$326	$368	1.00

SECTION VII

EXAMPLE APPLICATION OF M&R GUIDELINES
CONCRETE APRON FIELD CASE

This section provides an example application of the M&R guidelines of data collection, condition, evaluation, selection of feasible M&R alternatives, economic analysis, and selection of the optimum M&R alternative. The pavement used in this example is a concrete feature of an apron located in Louisiana. The primary traffic using the pavement is the KC-135 and B-52 aircrafts. The feature (Apron 13) serves as the immediate access to the three B-52 maintenance hangars shown in Figure 38. The pavement was originally constructed in 1945 with 11 inches of plain-jointed PCC over a lean clay and silt having a k-value of 75 pounds per cubic inch. The pavement was overlaid in 1955 with an additional 8 inc' ‐ PCC.

BACKGROUND

A condition evaluation am from the AFESC visited the airfield in May 1970 and found that the pr ent defect in the apron was longitudinal and transverse cracking in some slabs. The team concluded that the defect was load associated because they had noted that the pavement condition had degraded considerably since 1961, and in 1961 there had been very little longitudinal cracking. The evaluation showed that the subgrade strength in this area had degraded from a k of 75 to a k of 50 pounds per cubic inch. The main recommendation resulting from the evaluation was that the apron should be watched closely. The evaluation team predicted that it might be necessary to have the area overlaid during the next 10 years (from 1970).

DATA COLLECTION

The apron was surveyed in March 1978 by the base engineer, command engineer, and project staff to determine the optimum repair alternative. The feature consisted of 48 sample units, each of which was surveyed and the PCI determined (see Figure 39). Each sample unit consisted of 24 slabs, except sample units 33 through 36, which each contained 18 slabs. The slab size was 12 1/2 x 15 feet. Each sample unit was surveyed individually because after surveying several of the sample units at random, it was found that the PCI ranged from 10 to 98; thus, the standard deviation was very high. Therefore, it was decided that each slab should be surveyed to have accurate information for analyzing various M&R alternatives. Table 11 summarizes distress types, severities, and quantities for the feature.

Figures 40 through 42 are representative photographs of the distresses in the apron.

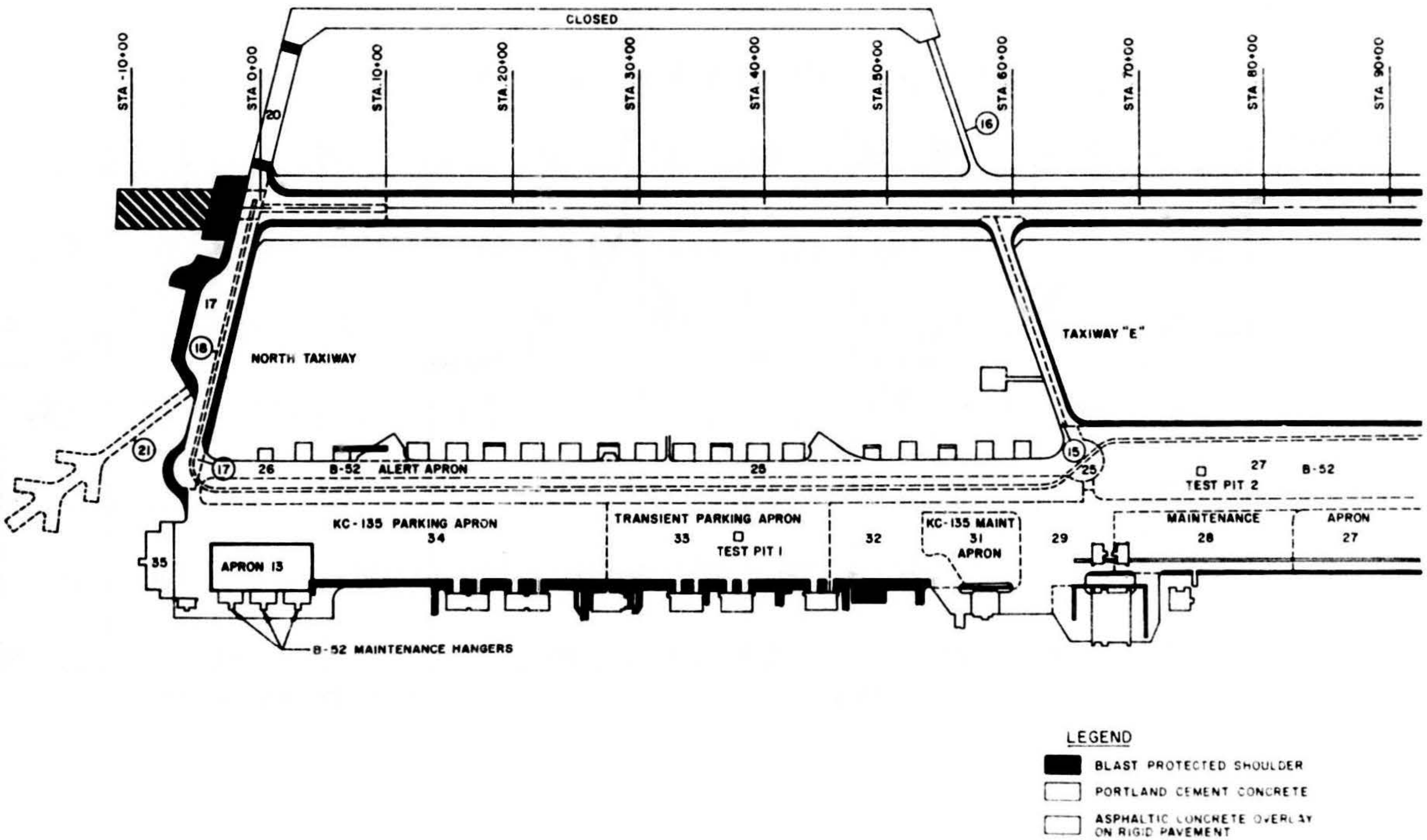


Figure 38. Portion of Airfield Showing Apron Under Consideration.

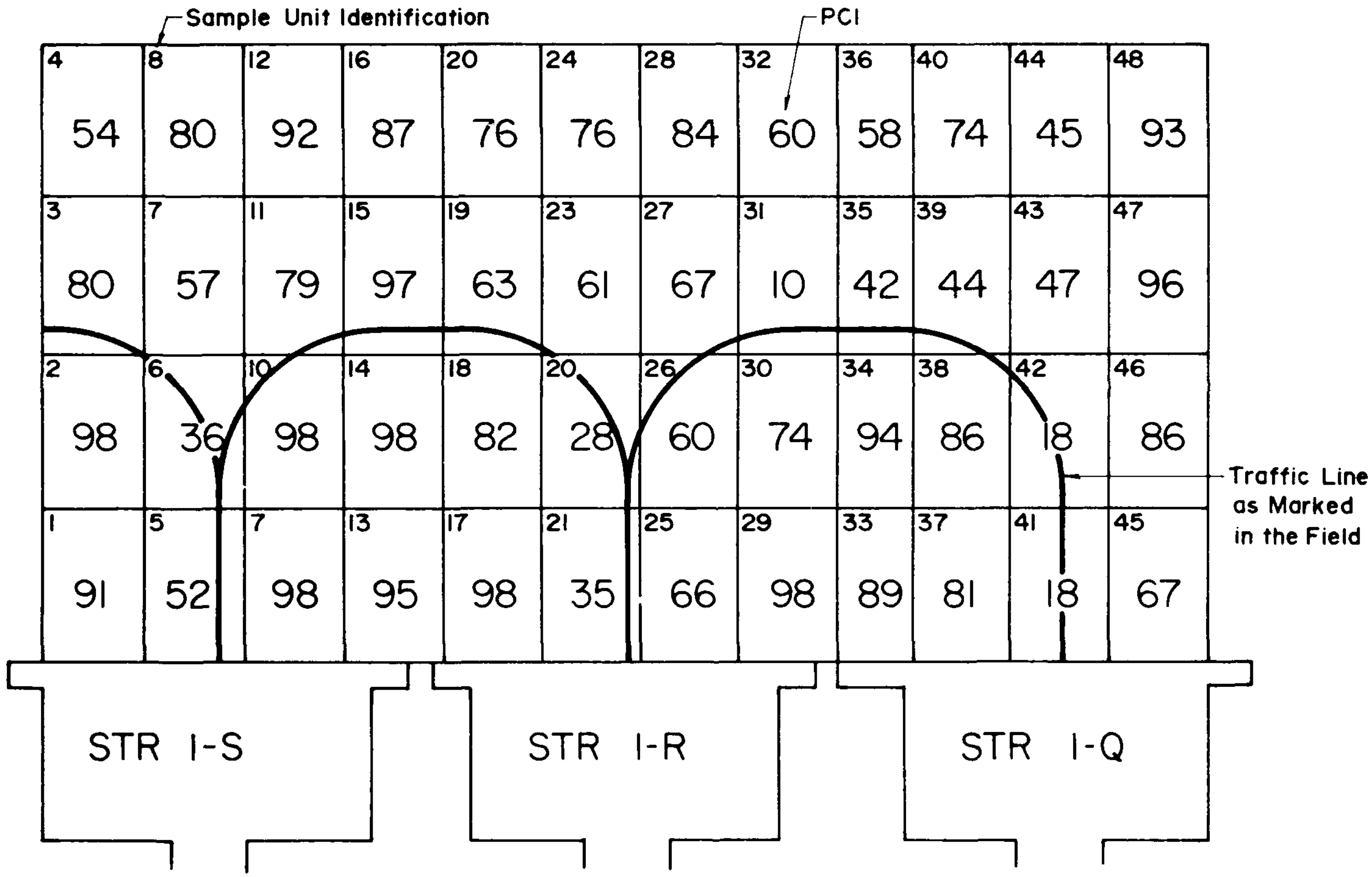


Figure 39. PCI for Individual Sample Units.

TABLE 11. SUMMARY OF DISTRESS FOR CONCRETE APRON FEATURE

Distress Type	Severity	Quantity (No. of Slabs)	Density (%)	Deduct Value	
Corner Break	Low	15	1.32	0.9	
Corner Break	Medium	13	1.15	2.0	
Corner Break	High	1	0.08	0.2	
Long/Trans Diag	Low	110	9.75	8.3	
Long/Trans/Diag	Medium	40	3.54	8.8	
Long/Trans/Diag	High	9	0.79	3.1	
Joint Seal Damage	Low	984	87.23	2.0	Overall Low
Joint Seal Damage	Medium	48	4.25	7.0	Severity
Small Patch	Low	8	0.70	0.1	
Small Patch	Medium	5	0.44	0.2	
Large Patch	Low	27	2.39	1.6	
Large Patch	Medium	4	0.35	0.8	
Large Patch	High	2	0.17	0.6	
Pumping		1	0.08	0.0	
Scaling/Crazing	Low	22	1.95	0.9	
Scaling/Crazing	Medium	5	0.44	0.6	
Settlement	Low	1	0.08	0.0	
Settlement	Medium	7	0.62	1.2	
Shattered Slab/Intersecting (Crack)	Low	15	1.32	3.3	
Shattered Slab/Intersecting (Crack)	Medium	16	1.41	7.0	
Shattered Slab/Intersecting (Crack)	High	31	2.74	22.1	
Shrinkage Crack		99	8.77	1.3	
Spalling, Joint	Low	10	0.88	0.5	
Spalling, Joint	Medium	3	0.26	0.2	
Spalling, Corner	Low	4	0.35	0.1	
Spalling, Corner	Medium	2	0.17	0.1	

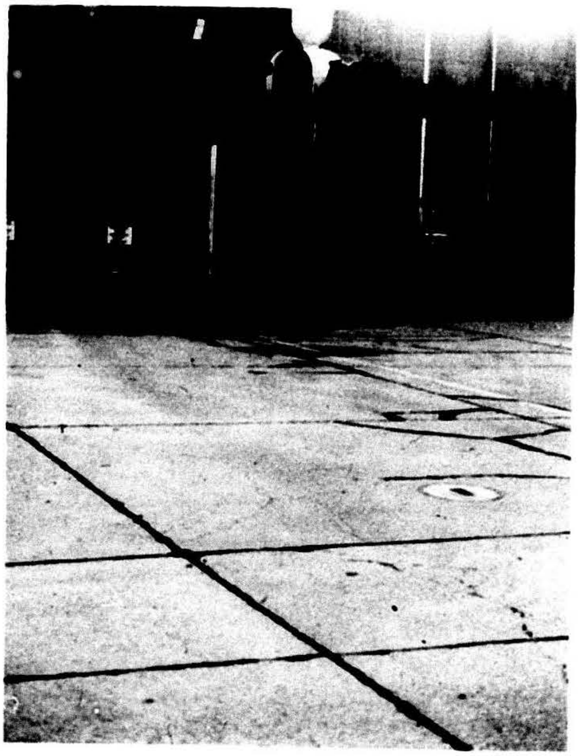


Figure 40. Pavement Damage Along Traffic Lines.

Figure 41. Severely Shattered Slab Located Along Traffic Line.

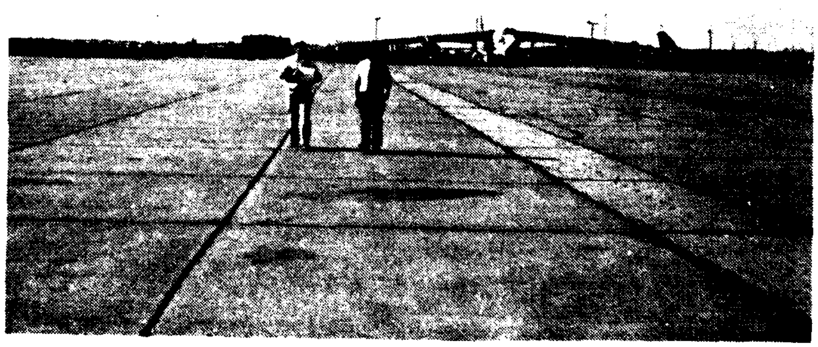


Figure 42. General View of Slabs in Apron.

CONDITION EVALUATION

Figure 43 summarizes the overall evaluation used for selecting feasible M&R alternatives. The mean PCI for the feature is 70, which corresponds to a condition rating of "good." The variation of PCI among sample units is great, however. From Figure 4, the sample unit critical minimum PCI is found to be 53 (for a mean PCI of 70), which far exceeds the lowest PCI of 10 found in the field. Therefore, there is localized random variation. A simple investigation of Figure 39 reveals that all the low PCI values occur along the B-52 traffic lines. The PCIs of sample units outside the traffic lines are generally very good, indicating a systematic variation. Dividing the feature into two separate features, based on the above findings, will probably eliminate both localized and systematic variations. However, if the feature is not divided, these variations should be strongly considered when selecting feasible M&R alternatives.

Table 12 gives a breakdown of the distress types and percent deduct values in terms of load and climate. The percent deduct value resulting from load-associated distress accounts for the majority of the total deduct value. Figure 44 shows the slabs containing key structural distress (cornerbreaks, longitudinal and transverse cracking, and/or shattered slabs). The majority of the distress occurred along the traffic lines.

The load-carrying capacity was evaluated (see Figure 45). The values used for the evaluation were:

Concrete flexural strength = 700 psi (as determined in 1970 by an Air Force evaluation team)

k subgrade = 50 pounds/cubic inch (as determined in 1970 by an Air Force evaluation team)

B-52 gross weight = 320 kips (based on a hangar load of 160 kips per gear)

Pavement thickness = 14 inches

The pavement thickness was determined by using the U.S. Army Corps of Engineers concrete overlay design equation (assuming a partial bond)

$$h_o = \sqrt[1.4]{h_n^{1.4} - Ch_e}$$

[Equation 7]
(Reference 5)

TABLE 12. SUMMARY OF DISTRESS EVALUATION FOR CONCRETE APRON

Distress Type		Deduct Value	Total Deduct (%)
Load-Associated Distress			
Corner Break		3.1	
Long/Trans Cracking		20.2	
Small Patch (< 5 square feet)		0.3 x 0.5*	
Large Patch (> 5 square feet)		3 x 0.5*	
Pumping		0.0	
Shattered Slab/Intersecting Crack		32.4	
Spalling Joint		0.7	
	SUBTOTAL	58.05	88%
Climate/Durability Associated Distress			
Joint Seal Damage		2	
Small Patch (< 5 square feet) (5%)		0.3 x 0.5*	
Large Patch (> 5 square feet) (5%)		3 x 0.5*	
Shrinkage Cracking		1.3	
Spalling, Corner		1.55	
	SUBTOTAL	6.65	10%
Other			
Settlement/Faulting		1.2	
	SUBTOTAL	1.2	
	TOTAL	65.9	2%

*50 percent of the deduct value for that distress was assumed to be from load and 50 percent from climate.

Facility: KC-135 Parking Apron Feature: Apron 13

1. Overall Condition Rating - PCI = 70

Excellent, Very Good, Good, Fair, Poor, Very Poor, Failed.

2. Variation of Condition Within Feature - PCI

   a. Localized Random Variation — Yes, No
   b. Systematic Variation: — Yes, No

3. Rate of Deterioration of Condition - PCI

   a. Long-term period (since construction) PCC overlay 1955 — Low, Normal, High
   b. Short-term period (1 year) — Low, Normal, High

4. Distress Evaluation

   a. Cause

   Load Associated Distress 88 percent deduct values
   Climate/Durability Associated 10 percent deduct values
   Other (___) Associated Distress 2 percent deduct values

   b. Moisture (Drainage) Effect on Distress — Minor, Moderate, Major
   c. Minimal Quality Sound Base Surface — satisfactory — Unsatisfactory

5. Load-Carrying Capacity Deficiency — No, Yes

6. Surface Roughness Not significant — Minor, Moderate, Major

7. Skid Resistance/Hydroplaning (runways only) not significant — No hydroplaning problems are expected

   a. Mu-Meter — Transitional; Potential for hydroplaning; Very high probability

   b. Stopping Distance Ratio — No hydroplaning anticipated; Potential not well defined; Potential for hydroplaning; Very high hydroplaning potential

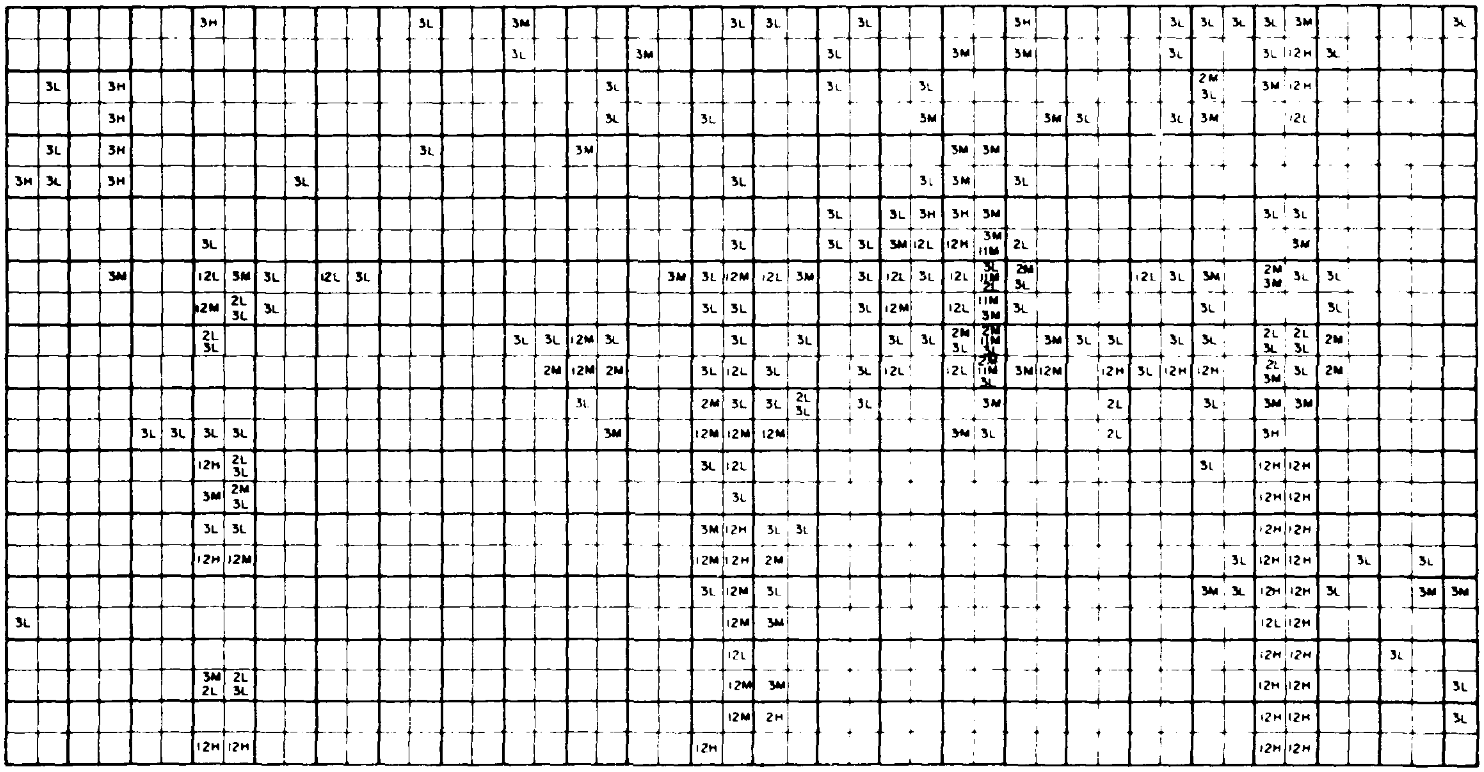
   c. Transverse Slope — Poor, Fair, Good, Excellent

8. Previous Maintenance — Low, Normal, High

9. Effect on Mission (Comments): FOD potential presents a problem. Asphalt surfacing should be avoided due to considerable oil spillage in the area.

Figure 43. Airfield Pavement Condition Evaluation Summary.

APRON 13 Individual Slabs Key Structural Distress*



* Distress Code	Distress Type	Distress Severity
2	Corner Break	L = Low
3	Long./Trans. Crk.	M = Medium
12	Shattered	H = High

Figure 44. Slabs Containing Key Structural Distress.

where h_o = overlay pavement thickness = 8 inches

h_e = existing pavement thickness before overlay = 11 inches

C = coefficient based on condition of existing pavement at time of overlay = 0.75 for initial corner cracking with no progressive cracking

h_n = thickness of new pavement.

By substituting into Equation 7, h_n is computed to be 14 inches. As shown in Figure 45, the number of load repetitions until cracking is determined to be 10. Therefore, the load-carrying capacity was classified as deficient.

Neither skid nor roughness were considered significant for the mission of the apron and were not evaluated. Based on a percent of large patch (more than 5 square feet) of 2.91, previous maintenance was classified as "normal."

FEASIBLE M&R ALTERNATIVES AND ECONOMIC ANALYSIS

The mean PCI for the entire feature is 70, which classifies the feature in the R-M-O Zone (Figure 15). In this zone, it is recommended that routine or major maintenance generally be applied, particularly if the pavement has a "good" rating. Overall repair should only be considered if one of the items on the evaluation sheet (Figure 43) is exceeded. In this case, the load-carrying capacity was determined to be deficient, and the load-associated distress contributed 88 percent of the total deduct value. Therefore, overall repair should be included as a feasible alternative. Another item that should receive serious consideration is the existence of systematic variation where the traffic area is in much worse condition than the rest of the apron.

Based on the evaluation results, four feasible alternatives were identified and an economic analysis performed. A 20-year analysis period was selected. The unit costs were based on the current prices for the area where the airfield is located (Table 13). Following is a description of each alternative.

Alternative No. 1: Perform Localized Repair as Needed

Selection of repair type was based on the alternatives presented in Table 3, including slab replacement, full-depth patching, partial-depth patching, crack sealing, and joint sealing. It was assumed that major localized repair would be repeated every 5 years during the analysis period. The number of slabs to be replaced during the first year was determined from the results of the condition survey. The number of slabs to be replaced in the future was estimated by assuming that within 20 years, every slab in the traffic area would have to be replaced. From Figure 46, the thickness of the new slabs was determined to be 19 inches. This thickness also matches the existing total thickness of concrete slabs (8 inches over 11 inches). Figure E-1 of Appendix E provides a detailed economic analysis.

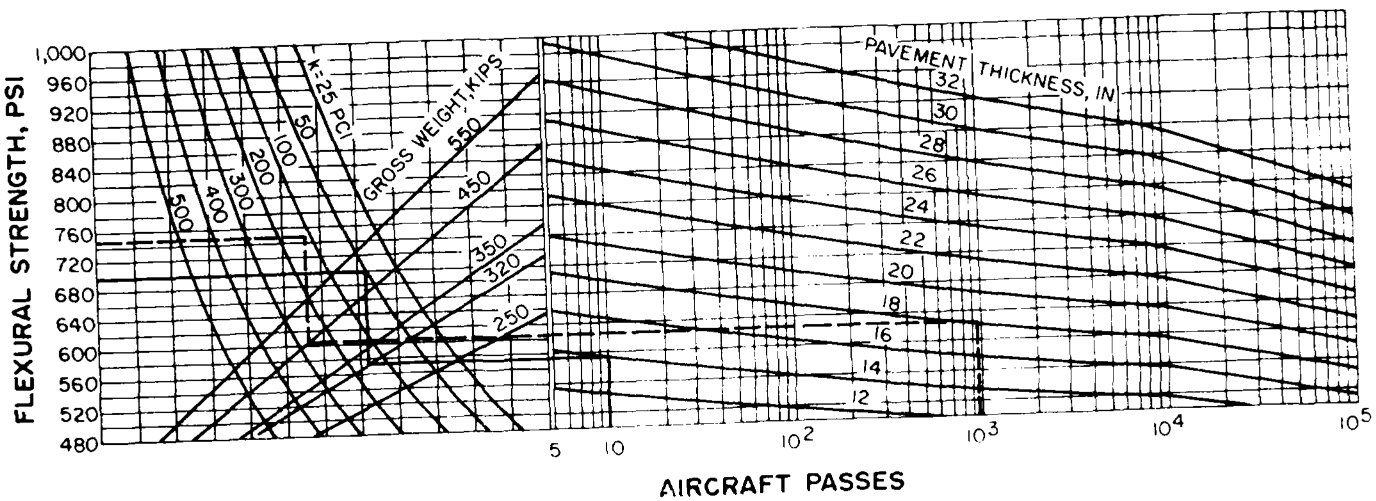
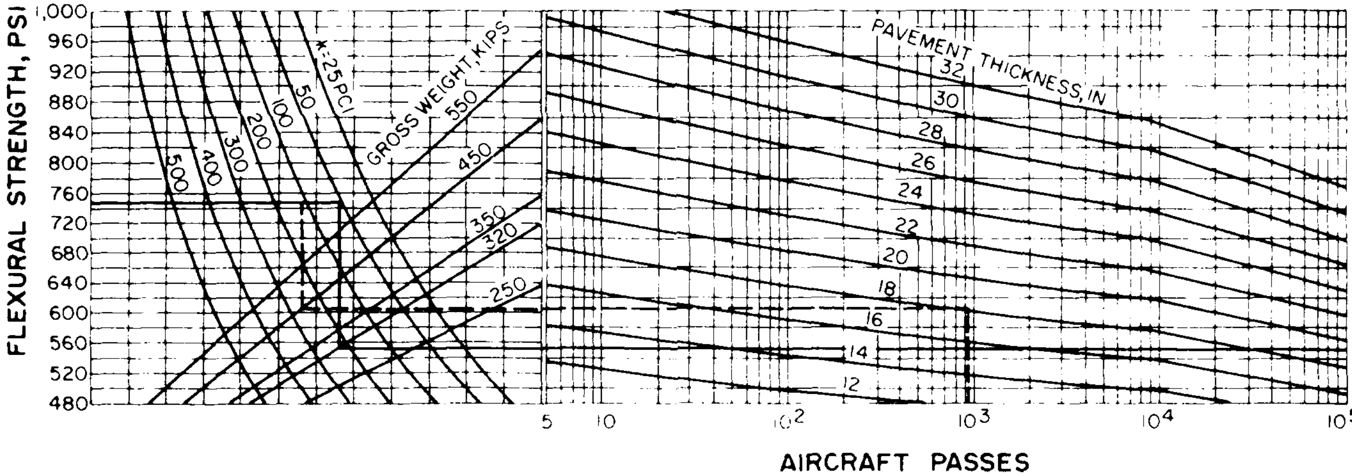


Figure 45. Load-Carrying Capacity Evaluation for Concrete Apron.

TABLE 13. UNIT COSTS FOR CONCRETE APRON

PCC Work	
Remove PCC Slab and Dispose of It	\$2.22/Square Yard/Inch or \$878.75/Slab (19 Inches, 12.5 x 15 Feet)
Complete Slab Replacement, One Slab at a Time	\$96.18/Square Yard/20 Inches
Remove Subbase Course Material and Dispose of It	\$0.63/Square Yard/Inch
Remove Subgrade Material and Dispose of It	\$0.63/Square Yard/Inch
Place Granular Material in Place Without Compaction	\$0.83/Square Yard/Inch
Prepare Subgrade (6 Inches)	\$0.91/Square Yard/6 Inches
Compact Granular Base	\$0.91/Square Yard/6 Inches
PCC in Place	\$80.00/Cubic Yards
Seal Slab Joints (New Construction)	\$0.20/Foot
Seal Old Slab Joints	\$0.31/Foot
Base (Cement or Lime) Stabilization in Place	\$0.26/Square Yard/Inch
AC in Place	\$30/Ton
Seal Slab Crack	\$0.35/Foot
Partially Depth-Patch PCC	\$3.33/Square Foot/Inch
Deep-Depth Patch PCC	\$4.37/Square Yard/Inch



Assumed Values:
Flexural Strength = 740 psi
K = 50 Pounds/Cubic Inch (existing)
Gross Weight = 320 kips (design value for hangers)
Number of Passes = 10^5

Figure 46. Determination of Required Thickness for Slab Replacement.

Alternative No. 2: Reconstruct Traffic Area

This alternative was selected based on the systematic variation identified during the pavement evaluation (Figures 43 and 45). Figure 47 illustrates the areas to be reconstructed. In addition to reconstruction, localized repair should be performed as needed. The exact area to be reconstructed can be slightly modified to reflect changes in expected traffic path. It is important that the traffic path be marked and followed by the mission aircraft. Figure E-2 of Appendix E provides the detailed economic analysis.

Alternative No. 3: Fully Bonded PCC Overlay

This alternative consists of replacing shattered and severely cracked slabs and overlaying with 7-inch concrete pavement. The overlay should be fully bonded using a bonding agent such as grout or epoxy; otherwise, a thicker overlay will be needed. In addition, the number of slabs to be replaced before placing the overlay is usually higher to insure high uniform quality. The overlay thickness was determined using the Corps of Engineers overlay equation for fully bonded concrete overlay:

$$h_o = h_n - h_e \qquad \text{[Equation 8]}$$

where h_n = required thickness = 21 inches (for flexural strength of 700 psi and k = 50 pounds per cubic inch

h_e = equivalent existing thickness = 14 inches

h_o = overlay thickness = 21 - 14 = 7 inches.

This alternative also includes feathering the overlay at a slope of 1 percent from the apron to the surrounding area. Figure E-3 of Appendix E gives the detailed economic analysis.

Alternative No. 4: Partially Bonded PCC Overlay

This alternative consists of replacing shattered and severely cracked slabs and overlaying with 10-inch concrete pavement. The number of slabs to be replaced was assumed to be the same as required in the first year of alternative 1.

The overlay thickness is determined using Equation 7.

$$h_o = {}^{1.4}\quad (h_n)^{1.4} - Ch_e^{\,1.4}$$

$$= {}^{1.4}\quad (21)^{1.4} - .75(19)^{1.4}$$

$$= 10 \text{ inches.}$$

Figure E-4 of Appendix E gives the detailed economic analysis; Table 14 summarizes the economic analysis results.

TABLE 14. SUMMARY COMPARISON OF M&R ALTERNATIVES
(ALL COSTS ARE TO THE NEAREST $1000)

Alternative	1978 Cost	Total Present Discounted Cost	SV	Present Worth	Ratio to Most Economical Alternative
1 (Localized)	138	546	279	267	5.1
2 (Reconstruct Traffic Area)	445	592	540	52	1.00
3 (Fully Bonded Overlay)	683	711	656	54	1.04
4 (Partially Bonded Overlay)	842	870	662	208	4.0

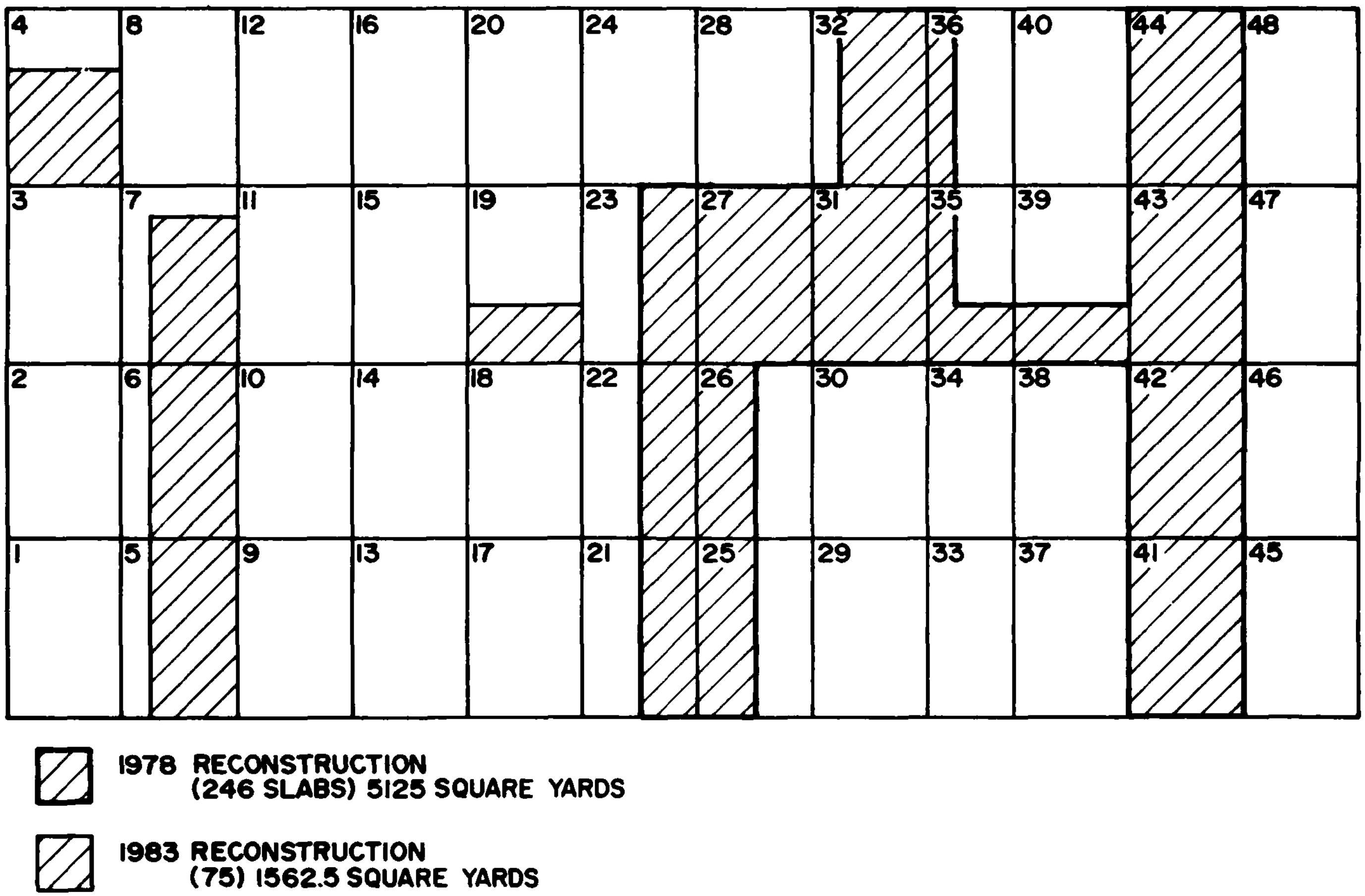


Figure 47. Alternative 2 -- Reconstruct the Shaded Area and Perform Localized Repair as Needed on Other Portion.

Alternatives 2 and 3 are by far the most economical, and alternative 2 also has the advantage of a lower initial cost (1978 cost). Adoption of alternative 3 (bonded overlay) will also require special adjustments in the levels of the floors of the B-52 maintenance hangers. On the other hand, by only structurally improving the current traffic area (alternative 2) caution should be taken to insure that aircraft movements are limited to the markings on the pavement.

At the time this report was prepared, the base engineer had identified a project based on alternative 2.

SECTION VIII

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY

The M&R guidelines and economic analysis procedures developed in FY77 (Reference 2) were field tested, improved, and validated. These procedures are data collection, condition evaluation, selection of feasible M&R alternatives, performance of economic analysis, and selection of the optimum M&R alternative. The application of these procedures was demonstrated for an asphalt runway in North Carolina and a concrete apron in Louisiana.

CONCLUSIONS

The procedures presented in this report were tested in several field applications, and were proven to be a rational and systematic approach to identifying feasible M&R alternatives and selecting optimum repair strategies. For both example applications demonstrated in this report, experienced base and command engineers have developed repair projects that implement the determined optimum M&R alternatives with minor or no modifications.

RECOMMENDATIONS

There are several feasible alternatives for repairing any given pavement, but the costs associated with the various alternatives are usually quite different. For example, the difference in PW between the most expensive and most economical alternatives was $249,000 (Table 10) for the asphalt runway and $215,000 for the concrete apron (Table 14). Considering that it only takes 1 to 2 man-weeks to analyze several M&R alternatives for a pavement feature, the amount of saving, and thus the return on investment, can be very high. It is therefore recommended that the analysis procedures presented in this report be implemented by the Air Force worldwide.

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APPENDIX A

EVALUATION SUMMARY FOR FEATURES R3C, R4C, R6C(B), R6C(A) -- ASPHALT RUNWAY FIELD CASE

Facility: Runway 5/23 Feature: R3C

1. Overall Condition Rating - PCI =57

Excellent, Very Good, Good, Fair, Poor, Very Poor, Failed.

2. Variation of Condition Within Feature - PCI

   a. Localized Random Variation — Yes, No
   b. Systematic Variation: — Yes, No

3. Rate of Deterioration of Condition - PCI

   a. Long-term period (since construction) Overlaid 1968 — Low, Normal, High
   b. Short-term period (1 year) Unknown — ~~Low, Normal, High~~

4. Distress Evaluation

   a. Cause (Extrapolated Data)

Load Associated Distress	62 percent deduct values
Climate/Durability Associated	38 percent deduct values
Other (___) Associated Distress	0 percent deduct values

   b. Moisture (Drainage) Effect on Distress — Minor, Moderate, Major

5. Load-Carrying Capacity Deficiency — No, Yes

6. Surface Roughness No info available — ~~Minor, Moderate, Major~~

7. Skid Resistance/Hydroplaning (runways only) — No hydroplaning problems are expected

   a. Mu-Meter — Transitional; Potential for hydroplaning; Very high probability

   b. Stopping Distance Ratio — No hydroplaning anticipated; Potential not well defined; Potential for hydroplaning; Very high hydroplaning potential

   c. Transverse Slope — Poor, Fair, Good, Excellent

8. Previous Maintenance — Low, Normal, High

9. Effect on Mission (Comments): (a) Long-time closure of runway will require mission relocation (b) It is better to plan short-time closures than to be forced to close due to severe deterioration.

Figure A-1. R3C Airfield Pavement Condition Evaluation Summary.

Facility: Runway 5/23 Feature: R4C

1. Overall Condition Rating - PCI = 81

Excellent, Very Good, Good, Fair, Poor, Very Poor, Failed.

2. Variation of Condition Within Feature - PCI

   a. Localized Random Variation — Yes, No
   b. Systematic Variation: — Yes, No

3. Rate of Deterioration of Condition - PCI

   a. Long-term period (since construction) Reconstr 1962 — Low, Normal, High
   b. Short-term period (1 year) Unknown — ~~Low, Normal, High~~

4. Distress Evaluation

   a. Cause (Extrapolated Data)

   Load Associated Distress — 50 percent deduct values
   Climate/Durability Associated — 50 percent deduct values
   Other (___) Associated Distress — 0 percent deduct values

   b. Moisture (Drainage) Effect on Distress — Minor, Moderate, Major

5. Load-Carrying Capacity Deficiency — No, Yes

6. Surface Roughness No info available — ~~Minor, Moderate, Major~~

7. Skid Resistance/Hydroplaning (runways only) — No hydroplaning problems are expected

   a. Mu-Meter — Transitional / Potential for hydroplaning / Very high probability

   b. Stopping Distance Ratio — No hydroplaning anticipated / Potential not well defined / Potential for hydroplaning / Very high hydroplaning potential

   c. Transverse Slope — Poor, Fair, Good, Excellent

8. Previous Maintenance — Low, Normal, High

9. Effect on Mission (Comments): Same as for R3C

Figure A-2. R4C Airfield Pavement Condition Evaluation Summary.

Facility: Runway 6/23 Feature: R6C(B)

1. Overall Condition Rating - PCI =81

Excellent, Very Good, Good, Fair, Poor, Very Poor, Failed.

2. Variation of Condition Within Feature - PCI

   a. Localized Random Variation — Yes, No
   b. Systematic Variation: — Yes, No

3. Rate of Deterioration of Condition - PCI

   a. Long-term period (since construction) 1954 — Low, Normal, High
   b. Short-term period (1 year) Unknown — ~~Low, Normal, High~~

4. Distress Evaluation

   a. Cause (Extrapolated Data)

      Load Associated Distress 51 percent deduct values
      Climate/Durability Associated 49 percent deduct values
      Other (___) Associated Distress 0 percent deduct values

   b. Moisture (Drainage) Effect on Distress — Minor, Moderate, Major

5. Load-Carrying Capacity Deficiency — No, Yes

6. Surface Roughness No info available — ~~Minor, Moderate, Major~~

7. Skid Resistance/Hydroplaning (runways only) — No hydroplaning problems are expected

   a. Mu-Meter — Transitional; Potential for hydroplaning; Very high probability

   b. Stopping Distance Ratio — No hydroplaning anticipated; Potential not well defined; Potential for hydroplaning; Very high hydroplaning potential

   c. Transverse Slope — Poor, Fair, Good, Excellent

8. Previous Maintenance — Low, Normal, High

9. Effect on Mission (Comments): Same as R3C

Figure A-3. R6C(B) Airfield Pavement Condition Evaluation Summary.

Facility: Runway 5/23 Feature: R6C(A)

1. Overall Condition Rating - PCI =51

Excellent, Very Good, Good, Fair, Poor, Very Poor, Failed.

2. Variation of Condition Within Feature - PCI

   a. Localized Random Variation — Yes, No
   b. Systematic Variation: — Yes, No

3. Rate of Deterioration of Condition - PCI

   a. Long-term period (since construction) 1954 — Low, Normal, High
   b. Short-term period (1 year) Unknown — ~~Low, Normal, High~~

4. Distress Evaluation

   a. Cause (Extrapolated Data)

   Load Associated Distress — 76 percent deduct values
   Climate/Durability Associated — 24 percent deduct values
   Other (___) Associated Distress — 0 percent deduct values

   b. Moisture (Drainage) Effect on Distress — Minor, Moderate, Major

5. Load-Carrying Capacity Deficiency — No, Yes

6. Surface Roughness No info available — ~~Minor, Moderate, Major~~

7. Skid Resistance/Hydroplaning (runways only) — No hydroplaning problems are expected

   a. Mu-Meter — Transitional; Potential for hydroplaning; Very high probability

   b. Stopping Distance Ratio — No hydroplaning anticipated; Potential not well defined; Potential for hydroplaning; Very high hydroplaning potential

   c. Transverse Slope — Poor, Fair, Good, Excellent

8. Previous Maintenance — Low, Normal, High

9. Effect on Mission (Comments): Same as R3C

Figure A-4. R6C(A) Airfield Pavement Condition Evaluation Summary.

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APPENDIX B

ECONOMIC ANALYSIS AMONG M&R ALTERNATIVES FOR FEATURE R2B -- ASPHALT R/W FIELD CASE

R2B Salvage Values

SV = cost of new construction over subgrade, keel section, for 20-year life cost of repair of this construction for another 20-year life

New Construction

Compact subgrade $= \frac{600 \times 75}{9} \times 0.5 = \$\ 2,500$

Place 6 inches gran. base $= \frac{600 \times 75}{27} \times 15 = \$12,500$

Compact base $= \$\ 2,500$

Place prime coat $= \frac{600 \times 75}{9}\ 0.10 = \$\ 0,500$

Place 8-inch AC $= 600 \times 75 \times (8/12) \times (145/2000) \times 30 = \$62,250$

$80,250

Localized Repair

Removal of AC surface at $0.30/square yard/inch = $ 9,000

Removal of base course at $0.20/square yard/inch = $ 8,000

Reconstruct AC pavement (6-inch AC + 6-inch granular) = $80,250

$97,250

SV, SV = 80,250 - 97,250 = - $17,000

Alternative No. 1

Scarify 4-inch AC and dispose of at $0.50/square yard/inch (keel section)	= $10,000
Place 4-inch AC at $30.00/ton	= 32,625
Routine M&R at $0.50/square yard	= 2,500
	$45,125
SV = 80,250-45,125	= $35,125

Alternative No. 2

Scarify and dispose of 2.0-inch AC at \$0.50/square yard/inch (keel section)	= \$ 5,000
Routine M&R at \$0.20/square yard	= \$ 1,000
Place 2.0-inch AC at \$30/ton	= \$16,312
	\$22,312
SV = 80,250 - 22,312	= \$57,938

Alternative No. 3

Scarify 2.5-inch AC and dispose of at \$0.50/square yard/inch (keel section)	= \$ 6,250
Fabric at \$1.25/square yard	= \$ 6,250
Place 2.5-inch AC at \$30/ton	= \$20,300
	\$32,890
SV = 80,250 - 32,890	= \$47,360

Alternative No. 4

Joint seal	= \$ 3,413
Routine M&R	= \$ 1,000
5 slab replacements at \$2000/slab	= \$10,000
	\$14,413
SV = 80,250 - 14,413	= \$65,837

Alternative No. 5

Joint seal	= \$ 3,413
Routine M&R	= \$ 1,000
2 slab replacements at \$2800/slab	= \$ 5,600
	\$10,013
SV = 80,250 - 10,013	= \$70,237

R2B

M & R ALTERNATIVE Continue Localized Repair As Needed For 20 Years

ANALYSIS PERIOD 20 **YEARS** **INTEREST RATE** 8 **%**

INFLATION RATE 6 **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1978	Deep patch medium severity alligator			
	crk (4.47% area) @ $18.5/SY	4,140	1.0	4,140
1978	Crack seal the low and medium severity			
	Joint reflection crk (.49% area) @ $.45/FT	100	1.0	100
1978	Crack seal low and medium severity			
	Long & Trans crk (2.45% area) @ $.45/FT	500	1.0	500
1978	Apply Rejuvenator @ $0.27/SY			
	(Keel-Section)	1,350	1.0	1,350
1980	Deep patch 6% area @ $18.5/SY	5,550	.963	5,345
1982	Deep patch 8% area @ $18.5/SY	7,400	.928	6,867
1984	Deep patch 10% area @ $18.5/SY	9,250	.894	8,270
1984	Crack seal and Rejuvenator	1,950	.894	1,743
1986	Deep patch 12% area @ $18.5/SY	11,100	.861	9,557
1988	Deep patch 14% area @ $18.5/SY	12,950	.830	10,749
1990	Deep patch 14% area @ $18.5/SY	12,950	.799	10,347
1990	Crack seal and Rejuvenator	1,950	.799	1,558
1992	Deep patch 14% area @ $18.5/SY	12,950	.770	9,972
1994	Deep patch 14% area @ $18.5/SY	12,950	.742	9,609
1996	Deep patch 14% area @ $18.5/SY	12,950	.714	9,246
			TOTAL	$89,353

SALVAGE VALUE = 17,000 x .688 = $ -11,696

PRESENT WORTH = $ 101,049

Figure B-1. Sample 1.

R2B (3+00 TO 9+00)

M & R ALTERNATIVE #1 Overlay the Entire Feature As Shown In Fig (1) With AC

ANALYSIS PERIOD 20 **YEARS** **INTEREST RATE** 8 **%**

INFLATION RATE 6 **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1978	Full-Depth Patching of Medium Severity Alligator Crk (2014 ft²) @ $1.75/SY/in AC & $1.00/SY/in Base	4,140	1.0	4,140
1978	Crack Seal the Low and Medium Severity Jt. Reflection Cracking (222 ft) @ $0.45/ft	100	1.0	100
1978	Crack Seal the Low and Medium Severity Long & Trans Cracking (1110 ft) @ $0.45/ft	500	1.0	500
1978	Place a tack coat on entire width (10,000 SY) @ $0.05/0.1 gal/SY	500	1.0	500
1978	Overlay the Section as shown in Fig (1) (6"-3.75"-1.5") (2039 Ton) @ $30.00/Ton	61,172	1.0	61,172
1978	Shoulders treatment 25 ft wide 69.4 CY @ $15.00/CY, material and processing	1,042	1.0	1,042
1978	Marking-paint (15% area) @ $1.75/SY	2,625	1.0	2,625
1978	Adjust Light Installation @ $3.00/Ft	3,600	1.0	3,600
1983	Routine M&R @ $0.30/SY Keel-Section	1,500	0.911	1,367
1988	Routine M&R @ $0.40/SY Keel-Section	2,000	0.830	1,660
1993	Routine M&R @ $0.50/SY Keel-Section	2,500	0.755	1,888
1996	Routine M&R @ $0.50/SY Keel-Section	2,500	0.714	1,785
			TOTAL	**$** 80,379

SALVAGE VALUE = 35,125 x 0.688 = **$** 24,166

PRESENT WORTH = **$** 56,213

Figure B-2. Sample 2.

R2B (3+00 To 9+00)

M & R ALTERNATIVE #2 Reconstruct Central 75-feet (keel-section) With 6.0-in AC on Asphalt Stabilized Base

ANALYSIS PERIOD 20 **YEARS** **INTEREST RATE** 8 **%**

INFLATION RATE 6 **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1978	Remove AC surface, keel-section			
	with Rotomill and Windrow			
	@ $0.50/SY/in	15,000	1.0	15,000
1978	Remove the 8-in Base Course			
	and dispose it @ $0.20/SY/in	8,000	1.0	8,000
1978	Place 3-in Granular Base @ $15/CY	6,250	1.0	6,250
1978	Compaction of Granular Base @ $0.10/SY	2,500	1.0	2,500
1978	Place the Recycled AC Surface			
	(≈5") as a base in two lifts			
	@ $0.25/SY/in	7,500	1.0	7,500
1978	Place a tack coat on top of			
	granular base @ $0.15/0.3 gal/SY	750	1.0	750
1978	Place 6-in AC Surface @			
	$30.00/Ton (1631 ton)	48,938	1.0	48,938
1978	Marking-paint (15% area) @			
	$1.75/SY	2,625	1.0	2,625
1983	Routine M&R @ $0.10/SY Keel-Section	500	0.911	456
1988	Routine M&R @ $0.20/SY Keel-Section	1,000	0.830	830
1993	Routine M&R @ $0.30/SY Keel-Section	1,500	0.755	1,133
1996	Routine M&R @ $0.30/SY Keel-Section	1,500	0.714	1,071
			TOTAL	$95,053

SALVAGE VALUE = 57,938 x 0.688 = $ 39,861

PRESENT WORTH = $ 55,192

Figure B-3. Sample 3.

R2B (3+00 To 9+00)

M & R ALTERNATIVE #3 Reconstruct Central 75-feet (keel-Section) with 6.0 inches AC on Cement Stabilized Base

ANALYSIS PERIOD 20 **YEARS** **INTEREST RATE** 8 **%**

INFLATION RATE 6 **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1978	Remove AC surface, keel-Section and dispose off @$0.30/SY/in	9,000	1.0	9,000
1978	Cement Stabilize 8-in Base Course in-place @$0.45/SY/in	18,000	1.0	18,000
1978	Place a tack coat on top of cement stabilized Base @ $0.05/0.1 gal/SY	250	1.0	250
1978	Place 6-in AC surface keel-Section @$30.00/Ton (1631 ton)	48,938	1.0	48,938
1978	Marking-paint (15% area) @ $1.75/SY	2,625	1.0	2,625
1983	Routine M+R @ $0.10/SY keel-Section	500	0.911	456
1988	Routine M&R @ $0.20/SY keel-section	1,000	0.830	830
1993	Routine M&R @$0.30/SY keel-section	1,500	0.755	1,133
1996	Routine M&R @$0.30/SY Keel-section	1,500	0.714	1,071
			TOTAL	$82,303

SALVAGE VALUE = 47,360 x 0.688 = $ 32,583

PRESENT WORTH = $ 49,720

Figure B-4. Sample 4.

R2B (3+00 To 9+00)

M & R ALTERNATIVE #4 Construct Central 75-feet, Keel-Section, with 10-in PCC on Cement Stabilized Base

ANALYSIS PERIOD 20 **YEARS** **INTEREST RATE** 8 **%**

INFLATION RATE 6 **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1978	Removal of existing AC surface			
	keel-section, and dispose off @			
	$0.30/SY/in	9,000	1.0	9,000
1978	Removal of 4 inches from			
	base course @ $0.20/SY/in	4,000	1.0	4,000
1978	Cement Stabilize 8 inches base			
	course (4 in base + 4 in subgrade) @			
	$0.45/SY/in	18,000	1.0	18,000
1978	Place 10-in PCC slab (18'x25')			
	@ $65.00/CY	90,278	1.0	90,278
1978	Joint Seal @ $0.70/ft	3,413	1.0	3,413
1978	Marking paint (12% area) @ $1.75/SY	2,625	1.0	2,625
1983	Routine M&R	1,000	.911	911
1985	Joint Seal @ $0.70/ft	3,413	.877	2,993
1988	Routine M&R	1,000	.830	830
1992	Joint Seal @ $0.70/ft	3,413	.770	2,628
1992	Routine M&R	1,000	.770	770
1996	Routine M&R	1,000	.714	714
			TOTAL	$ 136,162

SALVAGE VALUE = 65,835 × 0.688 = $ 45,295

PRESENT WORTH = $ 90,867

Figure B-5. Sample 5.

R2B (3+00 To 9+00)

M & R ALTERNATIVE #5 Construct Central 75-feet Keel-section, with 14-in PCC on Subgrade

ANALYSIS PERIOD 20 **YEARS** **INTEREST RATE** 8 **%**

INFLATION RATE 6 **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1978	Removal of AC surface keel-			
	Section, @ $0.30/SY/in	9,000	1.0	9,000
1978	Removal of the 8-in Base			
	Course @ $0.20/SY/in	8,000	1.0	8,000
1978	Subgrade leveling and Compaction			
	@ $0.75/SY	3,750	1.0	3,750
1978	Place 14-in PCC slabs (13'x25')			
	@ $65.00/CY	126,389	1.0	126,389
1978	Joint Seal @ $0.70/ft	3,413	1.0	3,413
1978	Marking-paint (15% bars) @ $1.75/SY	2,625	1.0	2,625
1983	Routine M&R	1,000	.911	911
1985	Joint Seal @ $0.70/ft	3,413	.877	2,993
1988	Routine M&R	1,000	.830	830
1992	Joint Seal @ $0.70/ft	3,413	.770	2,628
1992	Routine M&R	1,000	.770	770
1996	Routine M&R	1,000	.714	714
			TOTAL	$ 162,023

SALVAGE VALUE = 70,237 x 0.688 = **$** 48,323

PRESENT WORTH = **$** 113,700

Figure B-6. Sample 6.

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APPENDIX C

COMPARISON OF M&R ALTERNATIVES FOR
FEATURES R3C, R4C, R6C(B), AND R6C(A) --
ASPHALT R/W FIELD CASE

Feature R3C
9+00 to 16+00

Alternative No. 1:

Overlay the entire feature with AC. Localized repair must be performed before overlaying. Figure C-1 shows the cross-section of the overlay.

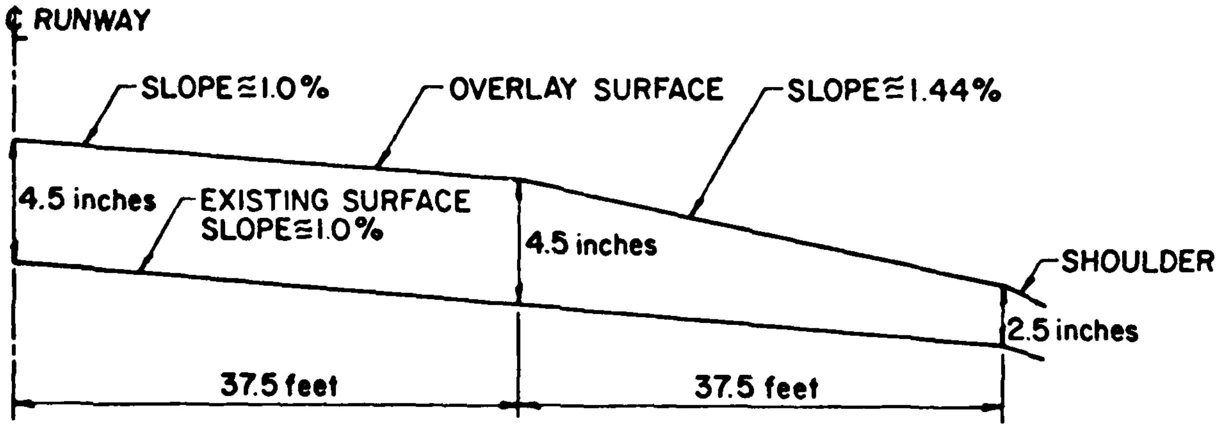


Figure C-1. Cross Section of Overlay for Feature R3C.

Alternative No. 2:

Remove base course and recycle AC surface, keel section. Place 4 inches of granular material on top of existing subgrade. Use recycled AC surface as a stabilized base course (approximately 5 inches). Add 5-inch surface course.

Alternative No. 3:

Remove the existing 6-inch surface, keel section, and add 1 inch of granular material. Cement stabilize, in place, a 9-inch base course. Place 5 inches of AC surface course.

Alternative No. 4:

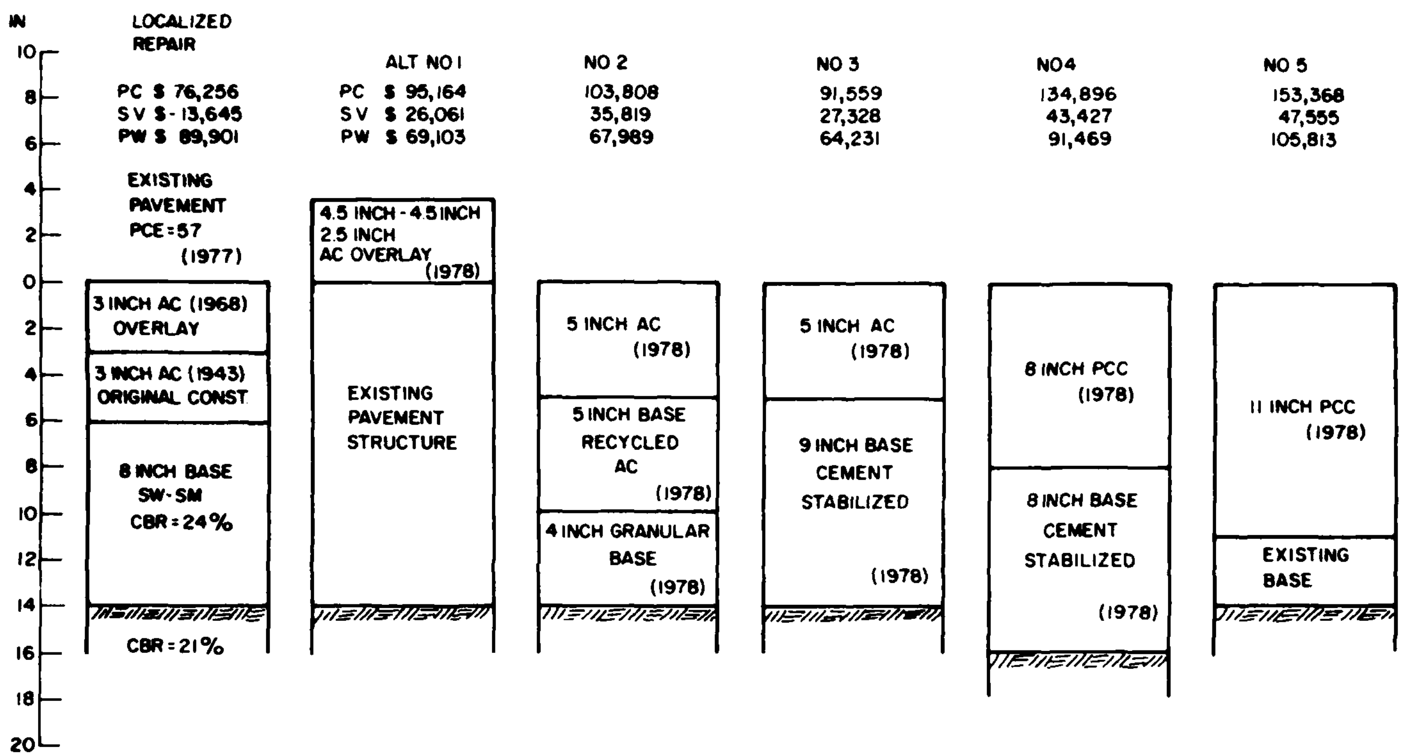
Remove the 6 inches of AC and 2 inches from the base course. Cement stabilize, in place, the 8-inch base course (6 inches remaining base + 2 inches subgrade material). Place 8-inch PCC slabs on keel section.

Alternative No. 5:

Remove the 6-inch AC surface and 5 inches from the base course. Place 11-inch PCC slabs on the keel section.

The five cross-sections of alternatives are shown in Table C-1, along with the PC, SV, and PW of each alternative.

TABLE C-1. REPAIR ALTERNATIVES FOR FEATURE R3C



Feature R4C
16+00 to 21+00

Alternative No. 1:

Overlay the entire feature with AC. Localized repair must be performed before overlaying. Figure C-2 shows the cross-section of the overlay.

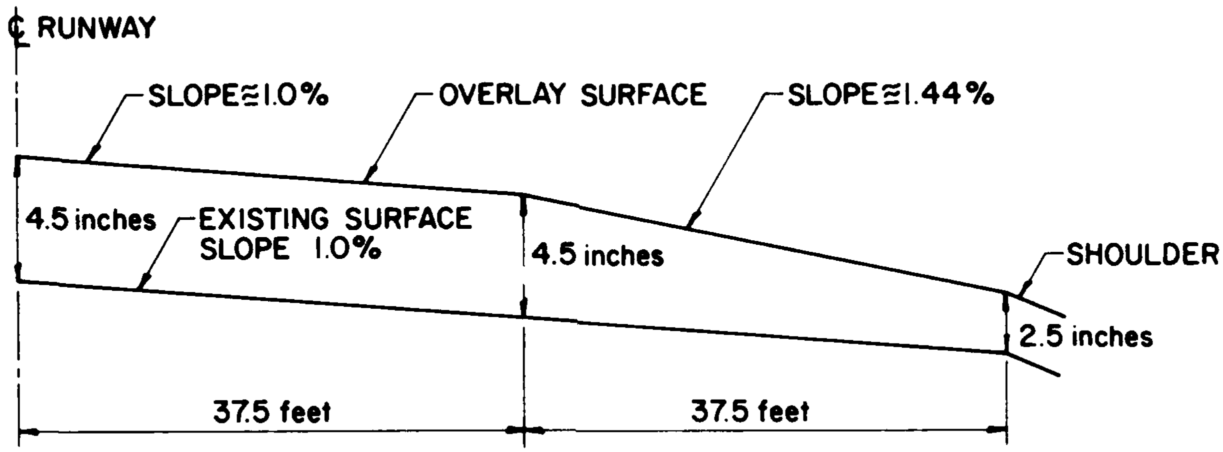


Figure C-2. Cross Section of Overlay for Feature R4C.

Alternative No. 2:

Remove base course and recycle AC surface, keel section. Place 4 inches of granular material on top of the existing subgrade. Use recycled AC surface as a stabilized base course (approximately 5 inches). Add a 5-inch AC surface.

Alternative No. 3:

Remove the existing 6-inch AC surface, keel, section, and add 1 inch of granular material. Cement stabilize, in place, the 9-inch base course. Place 5 inches of AC surface course.

Alternative No. 4:

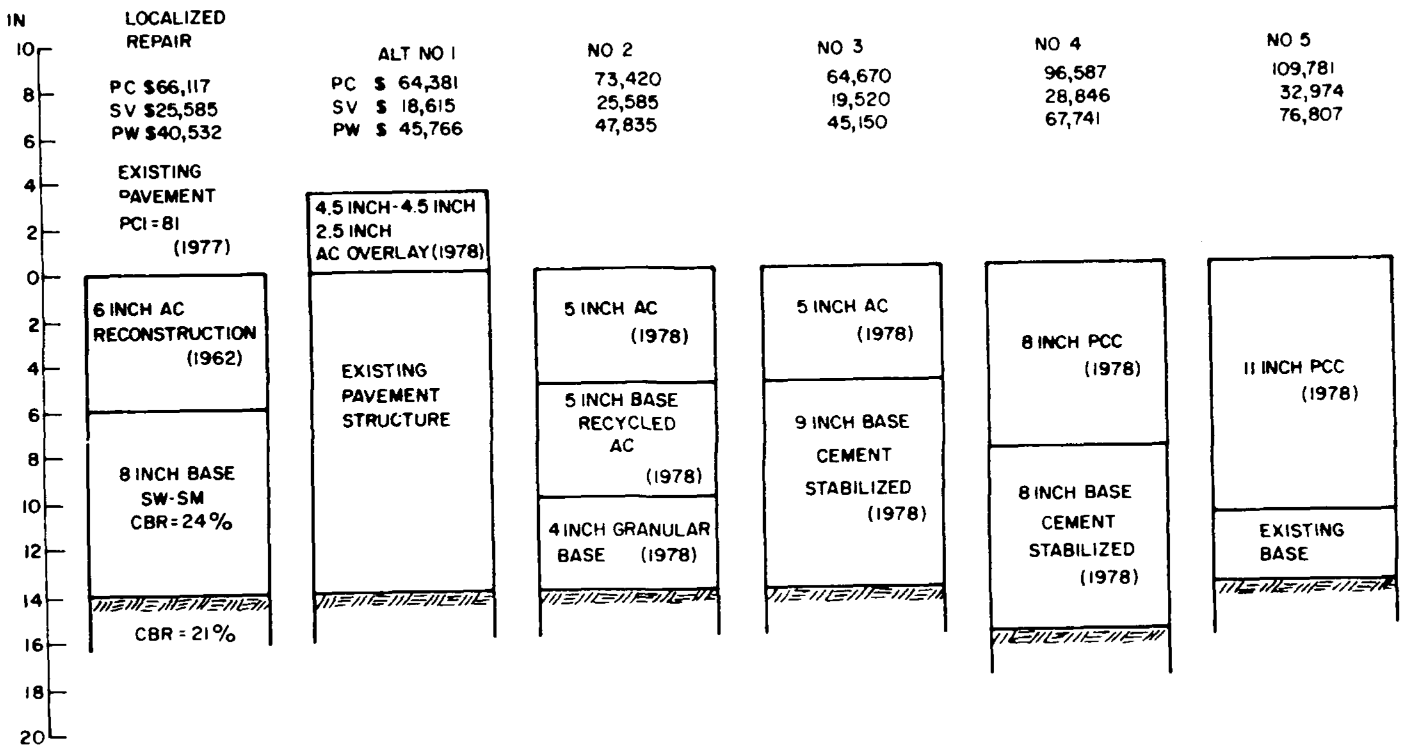
Remove the 6-inch AC and 2 inches from the base course. Cement stabilize, in place, the 8-inch base course (6 inches remaining base + 2 inches of subgrade material). Place 8-inch PCC slabs on keel section.

Alternative No. 5:

Remove the 6-inch AC surface and 5 inches from the base course. Place 11-inch PCC slabs on the keel section.

The five cross-sections of alternatives are shown in Table C-2, along with the PC, SW, and PW of each alternative.

TABLE C-2. REPAIR ALTERNATIVE FOR FEATURE R4C



Feature R6C (B)
50+00 to 57+50

Alternative No. 1:

Overlay the entire feature with AC. Localized repair must be performed before overlaying. The cross section of the overlay is shown in Figure C-3.

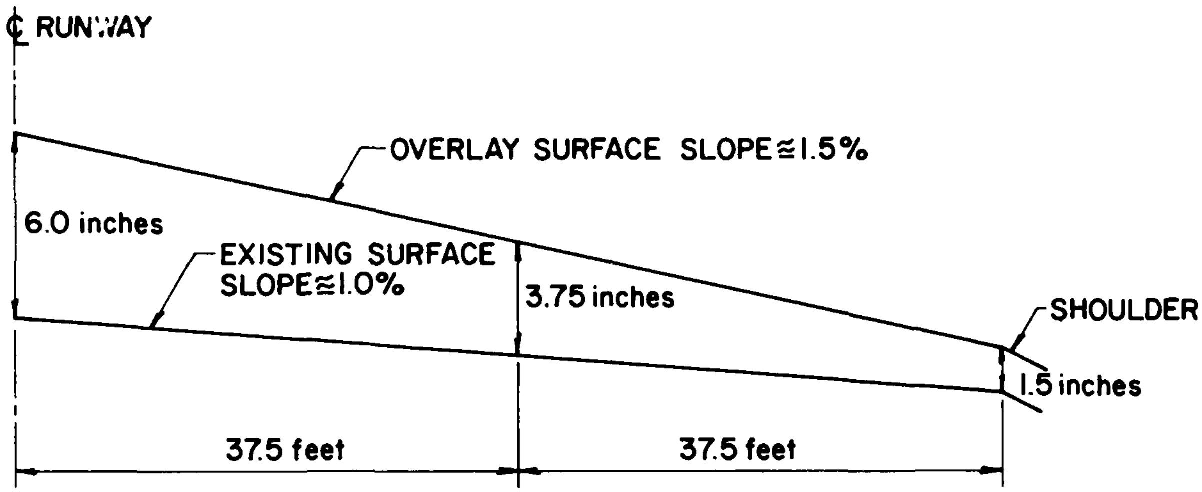


Figure C-3. Cross Section of Overlay for Feature R6C(B).

Alternative No. 2:

Remove base course and recycle the AC surface, keel section. Place 7 inches of granular material on top of the existing subgrade. Use the recycled AC surface as a stabilized base course (approximately 6.5 inches). Add a 5-inch AC surface course.

Alternative No. 3:

Remove the existing AC surface, keel section, and add 2.5 inches of granular material. Cement stabilize, in place, an 11-inch base course. Place 5 inches of AC surface course.

Alternative No. 4:

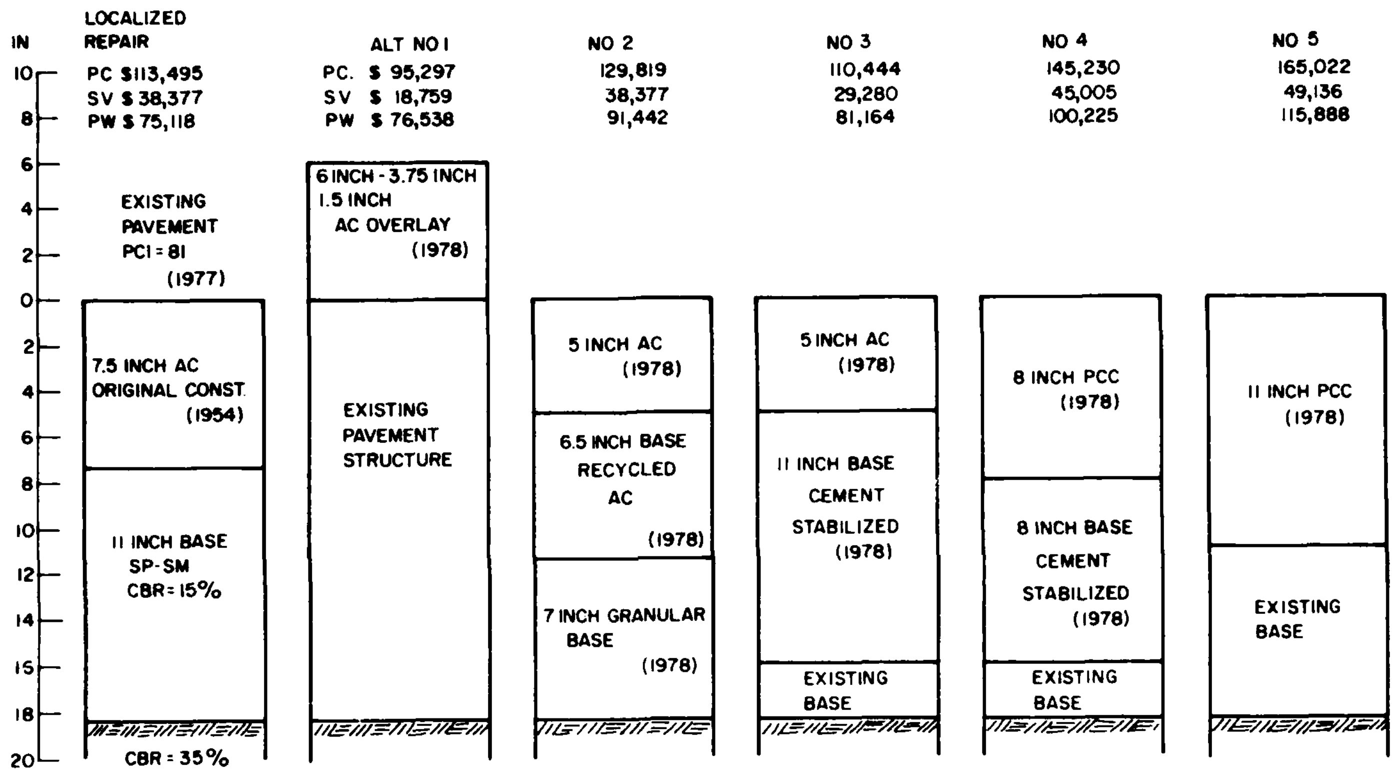
Remove the 7.5-inch AC surface and 0.5 inch from the base course. Cement stabilize, in place, an 8-inch base course, and place 8-inch PCC slabs on the keel section.

Alternative No. 5:

Remove the AC surface and 3.5 inches from the base course. Place 11-inch PCC slabs on the keel section.

The five cross sections of alternatives are shown in Table C-3, along with the present PC, SV, and PW of each alternative.

TABLE C-3. REPAIR ALTERNATIVES FOR FEATURE R6C(B)



Feature R6C(A)
57+50 to 65+00

Alternative No. 1:

Overlay the entire feature with AC. Localized repair must be performed before overlaying. The cross section of the overlay is shown in Figure C-4.

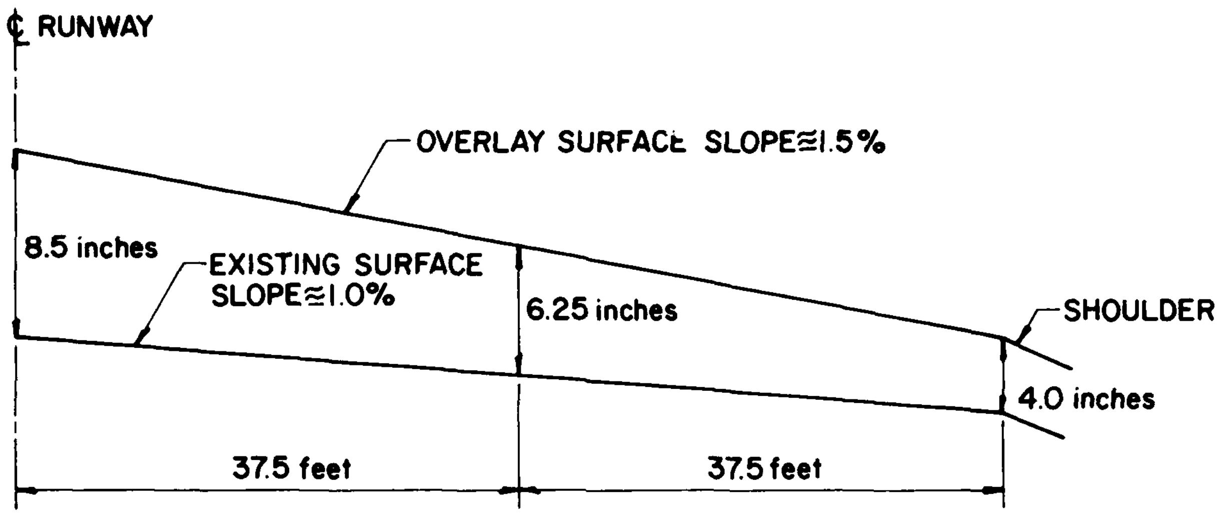


Figure C-4. Cross Section of Overlay for Feature R6C(A).

Alternative No. 2:

Remove the base course and recycle the AC surface, keel section. Place 7 inches of granular material on top of the existing subgrade. Use the recycled AC surface as a stabilized base course (approximately 4 inches). Add a 5-inch AC surface course.

Alternative No. 3:

Remove the existing AC surface, keel section, and replace it with another 5-inch AC surface after stabilizing the 11-inch base course with cement (in place).

Alternative No. 4:

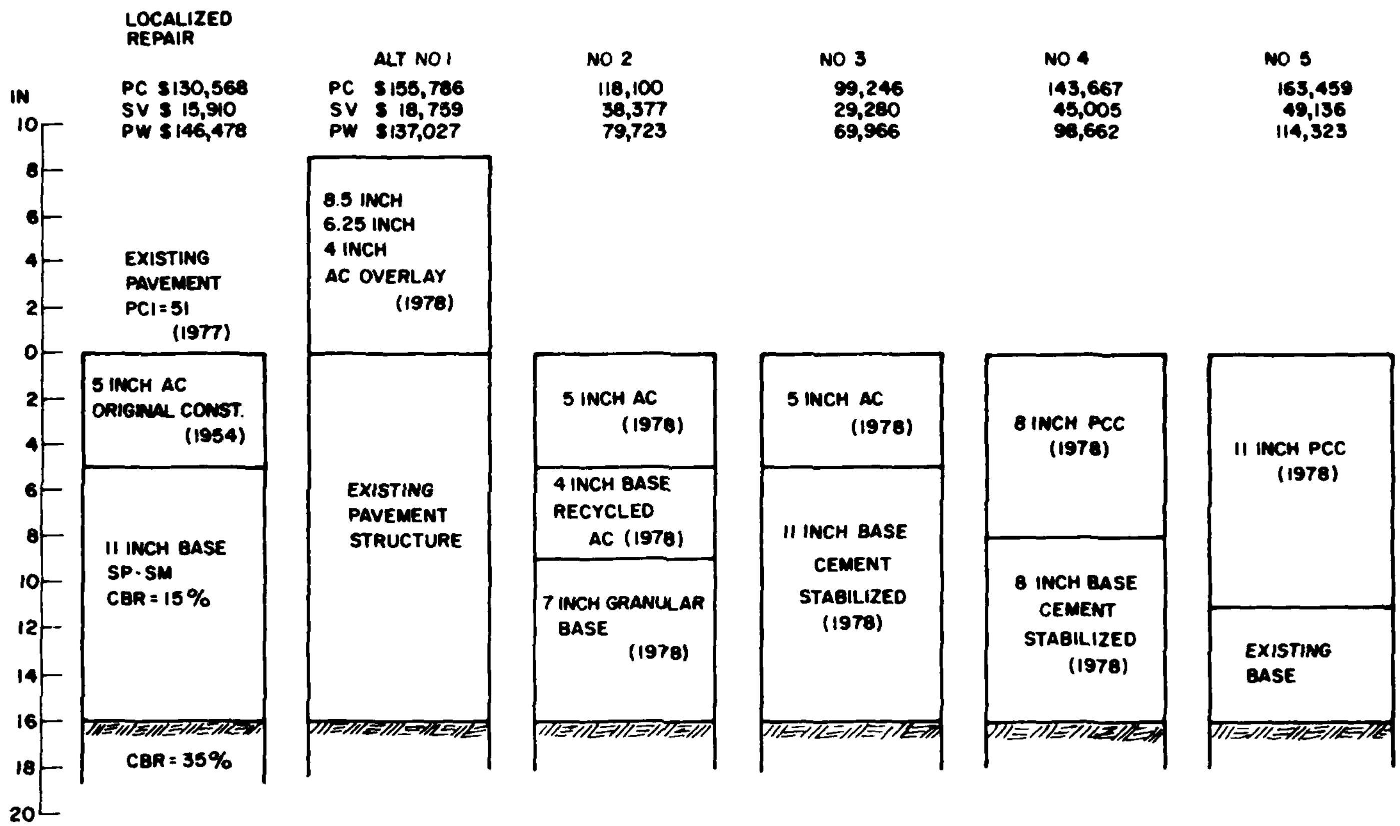
Remove the 5-inch AC surface and 3 inches from the base course. Cement stabilize, in place, the 8-inch remaining base course, and place 8-inch PCC slabs on the keel section.

Alternative No. 5:

Remove the AC surface and 6 inches from the base course. Place 11-inch PCC slabs on the keel section.

The five cross-sections of alternatives are shown in Table C-4 with the PC, SV, and PW of each alternative.

TABLE C-4. REPAIR ALTERNATIVES FOR FEATURE R6C(A)



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APPENDIX D

ECONOMIC ANALYSIS OF M&R ALTERNATIVES FOR ENTIRE ASPHALT RUNWAY

Entire Runway Salvage Values

Alternative No. 1

Salvage Value of R2A	= $ 57,938
Salvage Value of R3C	= $ 52,063
Salvage Value of R4C	= $ 27,056
Salvage Value of R5C	= $156,932
Salvage Value of R6C(B)	= $ 27,266
Salvage Value of R6C(A)	= $ 55,781
	$377,036

Alternative No. 2

Salvage Value of R2A	= $ 35,125
Salvage Value of R3C	= $ 37,880
Salvage Value of R4C	= $ 27,056
Salvage Value of R5C	= $156,932
Salvage Value of R6C(B)	= $ 27,266
Salvage Value of R6C(A)	= $ 27,266
	$311,525

Alternative No. 3

Salvage Value of R2A	= $ 47,360
Salvage Value of R3C	= $ 39,721
Salvage Value of R4C	= $ 28,372
Salvage Value of R5C	= $146,510
Salvage Value of R6C(B)	= $ 42,558
Salvage Value of R6C(A)	= $ 42,558
	$347,079

Alternative No. 4

Salvage Value of R2A	= $ 65,835
Salvage Value of R3C	= $ 63,121
Salvage Value of R4C	= $ 41,928
Salvage Value of R5C	= $146,510
Salvage Value of R6C(B)	= $ 65,419
Salvage Value of R6C(A)	= $ 65,419
	$448,232

Alternative No. 5

Salvage Value of R2A	= $ 70,237
Salvage Value of R3C	= $ 69,121
Salvage Value of R4C	= $ 47,928
Salvage Value of R5C	= $146,510
Salvage Value of R6C(B)	= $ 71,419
Salvage Value of R6C(A)	= $ 71,419
	$476,634

Alternative No. 6

Salvage Value of R2A	= $ 57,938
Salvage Value of R3C	= $ 52,063
Salvage Value of R4C	= $ 37,187
Salvage Value of R5C	= $215,687
Salvage Value of R6C(B)	= $ 55,781
Salvage Value of R6C(A)	= $ 55,781
	$474,437

AC R/W 5/23 (3+00 To 65+00)

M & R ALTERNATIVE #1 Reconstruct Keel-Section of R2B, R3C and R6C(A), Overlay R4C, R5C and R6C(B) After Removal of 1"

ANALYSIS PERIOD 20 **YEARS** **INTEREST RATE** 8 **%**

INFLATION RATE 6 **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
	Reconstruct Keel-Section of R2B			
	R3C and R6C(A) with AC on Asphalt			
	Stabilized Base (Rotomill) (Present			
	Worth for 20 Years)			316,961
1978	Scarify 1-in AC, Keel-Section of			
	R4C, R5C and R6C(B) @ $0.50/SY/IN	17,292	1.0	17,292
1978	Place 4-in AC Surface on Keel-			
	Sections, then Feather it out			
	to 1-in on shoulders @ $30.00/Ton	338,484	1.0	338,484
1978	Shoulders Treatment 5' Wide			
	@ $15.00/CY	961	1.0	961
1978	Marking-paint	13,197	1.0	13,197
1978	Adjust and Renew Light			
	Installations @ $3.00/Ft	24,900	1.0	24,900
1983	Routine M&R @ $0.30/SY Keel-Section	10,375	.911	9,452
1988	Routine M&R @ $0.40/SY Keel-Section	13,833	.830	11,482
1993	Routine M&R @ $0.50/SY Keel-Section	17,292	.755	13,055
1996	Routine M&R @ $0.50/SY Keel-Section	17,292	.714	12,346
			TOTAL	**$**758,130

SALVAGE VALUE = 377,036 X 0.688 = **$** 259,400

PRESENT WORTH = **$** 498,730

Figure D-1. Sample 1.

AC R/W 5-23 (3+00 To 65+00)

M & R ALTERNATIVE #2 Overlay the Entire AC Surface As Shown on Fig. 33

ANALYSIS PERIOD 20 **YEARS** **INTEREST RATE** 8 **%**

INFLATION RATE 6 **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1978	Perform Localized Repair on Entire AC Surface	29,359	1.0	29,359
1978	Place Tack Coat on Entire Width @ $0.05/.1gal/SY	5,167	1.0	5,167
1978	Overlay the AC Surface as Shown in Fig (2)(18,578T)@ $30.00/Ton	557,344	1.0	557,344
1978	Shoulders Treatment @ $15.00/CY	7,500	1.0	7,500
1978	Marking - paint	22,166	1.0	22,166
1978	Adjust and Rewire Light Installations @ $300/Ft	37,200	1.0	37,200
1983	Routine M&R @ $0.30/SY (keel-Section)	15,500	.911	14,121
1988	Routine M&R @ $0.40/SY (Keel-Section)	20,667	.830	17,153
1993	Routine M&R @ $0.50/SY (Keel-Section)	25,833	.755	19,504
1996	Routine M&R @ $0.50/SY (Keel-Section)	25,833	.714	18,445
			TOTAL	$727,959

SALVAGE VALUE = 311,525 x 0.688 = **$** 214,329

PRESENT WORTH = $ 513,630

Figure D-2. Sample 2.

AC R/W 5/23 (3+00 To 65+00)

M & R ALTERNATIVE #3 Reconstruct Central 75 Feet With AC on Cement Stabilized Base and Replace 3" AC Surface of R5C

ANALYSIS PERIOD 20 **YEARS** **INTEREST RATE** 8 **%**

INFLATION RATE 6 **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
	R2B			82,303
	R3C			91,559
	R4C			64,670
	R5C (3" AC Replacement)			181,047
	R6C(B)			110,444
	R6C(A)			99,246
			TOTAL	$629,269

SALVAGE VALUE = 347,079 x 0.688 = $ 238,790

PRESENT WORTH = $ 390,479

Figure D-3. Sample 3.

AC R/W 5/23 (3+00 To 65+00)

M & R ALTERNATIVE #4 Construct Keel-Section With PCC on Cement Stabilized Base and Replace 3" AC Surface of R5C

ANALYSIS PERIOD 20 **YEARS** **INTEREST RATE** 8 **%**

INFLATION RATE 6 **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
	R2B - 10" PCC			136,162
	R3C - 8" PCC			134,896
	R4C - 8" PCC			96,587
	R5C - 3" AC Replacement			181,047
	R6C(B) - 8" PCC			145,230
	R6C(A) - 8" PCC			143,067
			TOTAL	$866,589

SALVAGE VALUE = 448,232 x 0.688 = **$** 308,384

PRESENT WORTH = $ 558,205

Figure D-4. Sample 4.

AC R/W 5/23 (3+00 To 65+00)

M & R ALTERNATIVE #5 Construct Keel-Section With PCC on Subgrade and Replace 3" AC Surface of R5C

ANALYSIS PERIOD 20 **YEARS** **INTEREST RATE** 8 **%**

INFLATION RATE 6 **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
	R2B - 14" PCC			162,023
	R3C - 11" PCC			153,368
	R4C - 11" PCC			109,781
	R5C - 3" AC Replacement			181,047
	R6C(B) - 11" PCC			165,022
	R6C(A) - 11" PCC			163,459
			TOTAL	$944,700

SALVAGE VALUE = 476,634 x 0.688 = **$** 327,924

PRESENT WORTH = $ 616,776

Figure D-5. Sample 5.

AC R/W 5/23 (3+00 To 65+00)

M & R ALTERNATIVE #6

ANALYSIS PERIOD 20 **YEARS** **INTEREST RATE** 8 **%**

INFLATION RATE 6 **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1978-1988	Localized Repair on R4C			
1988	Reconstruct Keel-Section with			
	5-in AC on Asphalt Stabilized Base			66,117
1978-1988	Localized Repair on R6C(B)			
1988	Reconstruct Keel-Section with			
	5-in AC on Asphalt Stabilized Base			113,495
1978-1988	Localized Repair on R5C			
1988	Replace 3-inches AC surface			195,786
1979	Reconstruct Keel-Section of R6C(A)			
	with 5-in AC on Asphalt Stabilized			
	Base			115,939
1979	Reconstruct Keel-Section of R2B			
	with 6-in AC on Asphalt Stabilized			
	Base			93,313
1979	Reconstruct Keel-Section of R3C			
	with 6-in AC on Asphalt Stabilized			
	Base			108,863
			TOTAL	$693,513

SALVAGE VALUE = 474,437 X 0.688 = **$** 326,413

PRESENT WORTH = **$** 367,100

Figure D-6. Sample 6.

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APPENDIX E

ECONOMIC ANALYSIS OF M&R ALTERNATIVES FOR CONCRETE APRON FIELD CASE

Alternative No. 1

Rehabilitation cost; 300 slab replacements	$570,000
Localized repair	$ 10,000
Joint seal	$ 10,000
	$590,000
SV = 995,333 - 590,000 = (current prices)	$405,333

Alternative No. 2

Rehabilitation cost; 100 slab replacements	$190,000
Localized repair	$ 10,000
Joint seal	$ 10,000
	$210,000
SV = 995,333 - 210,000 = (current prices)	$785,333

Alternative No. 3

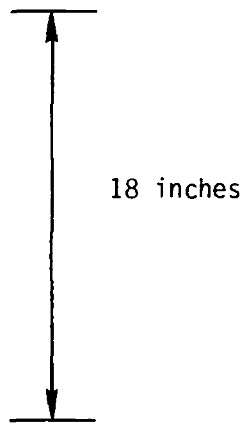
Rehabilitation costs; 10 slab replacements at $2600	$26,000
Localized maintenance	$ 5,000
Joint seal	$10,000
	$41,000
SV = 995,333 - 41,000 = (current prices)	$954,333

Alternative No. 4

Rehabilitation costs; 10 slab replacements at $1800	$ 18,000
Localized maintenance	$ 5,000
Joint seal	$ 10,000
	$ 33,000
SV = 995,333 - 33,000 = (current prices)	$962,333

Computation of SV

New Construction



Lime-stabilized subgrade
K 200 pounds per cubic inch

Lime stabilization at \$0.26/square yard/inch

$$= \left(\frac{705 \times 300}{9}\right) \times 8 \text{ inches} \times .26 = \quad \$\ 48{,}880$$

8-inch PCC at \$80/cubic yard

$$= \frac{705 \times 300}{27} \times 18/12 \quad 18/12 \times 80 \quad = \$\ 940{,}000$$

joint seal at \$0.2/foot = \$ 6,453

Total New Construction Cost = \$ 995,333

M & R ALTERNATIVE #1 Localized Repair as Needed Every 5 Years

ANALYSIS PERIOD 20 **YEARS** **INTEREST RATE** 8 **%**

INFLATION RATE 6 **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1978	Slab Replacement with 19" PCC			
	(67 slabs) @ $1900/Slab	127,300	1.0	127,300
1978	Full-Depth Patching of 14 Slabs			
	(≈5'x5'x19") @ $4.37/SY/IN	3,229	1.0	3,229
1978	Partial-Depth Patching of 19 Slabs			
	(≈5'x5'x4") @ $3.33/SF/IN	6,327	1.0	6,327
1978	Crack Seal 151 Slabs (≈15'x15')			
	@ $0.35/Ft	793	1.0	793
1983	Slab Replacement with 19" PCC			
	(70 slabs) @ $1900/Slab	133,000	.911	121,163
1983	Patching @ $4.37/SY/IN (21 Slabs)	5,000	.911	4,555
1983	Crack Seal @ $0.35/Ft (190 Slabs)	1,000	.911	911
1985	Joint Seal 32,265/Ft @ $0.31/Ft	10,000	.877	8,770
1988	Slab Replacement with 19" PCC			
	(80 slabs) @ $1900/Slab	152,000	.830	126,160
1988	Patching @ $4.37/SY (21 slabs)	5,000	.830	4,150
1988	Crack Seal @ $0.35/Ft (200 slabs)	1,050	.830	872
1992	Joint Seal 32,265/Ft @ $0.31/Ft	10,000	.770	7,700
1993	Slab Replacement with 19" PCC			
	(90 slabs) @ $1900/Slab	171,000	.755	129,105
1993	Patching @ $4.37/SY/IN (21 slabs)	5,000	.755	3,775
1993	Crack Seal @ $0.35/Ft (200 Slabs)	1,050	.755	793
			TOTAL	$545,603

SALVAGE VALUE = 405,333 X 0.688 = $ 278,869

PRESENT WORTH = $ 266,733

Figure E-1. Sample 1.

M & R ALTERNATIVE #2 Reconstruction of Shaded Areas As Shown On Fig (3) Plus Localized Repair On Others

ANALYSIS PERIOD 20 **YEARS** **INTEREST RATE** 8 **%**

INFLATION RATE 6 **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1978	Removal of PCC Slabs & Dispose			
	Off @ $2.22/SY/IN (5125 SY)	216,173	1.0	216,173
1978	Lime Stabilize 6-in Subgrade @			
	$0.26/SY/IN	10,660	1.0	10,660
1978	Place 19" PCC Slab @ $80/CY	216,389	1.0	216,389
1978	New Slab Joints Seal @ $0.20/ft			
	(≈ 7850 ft)	1,570	1.0	1,570
1978	Crack Seal ≈ 50 Slabs (50 x 15') @			
	$0.35/ft	263	1.0	263
1983	Removal of PCC Slabs & Dispose			
	off @ $2.22/SY/IN (1562.5 SY)	65,906	.911	60,041
1983	Subgrade Prep. @ $0.91/SY	1,422	.911	1,295
1983	Place 19" PCC Slabs @ $80/CY	65,992	.911	60,101
1983	New Slab Joints Seal @ $0.20/ft			
	(≈ 2515 ft)	503	.911	458
1988	Localized Repair @ $0.20/SY	4,700	.830	3,901
1988	Joint Seal	10,000	.830	8,300
1993	Localized Repair @ $0.30/SY	7,050	.7[illegible]	5,2[illegible]
1995	Joint Seal	10,000	.728	7,280
			TOTAL	$591,755

SALVAGE VALUE = 785,333 x 0.688 = **$** 540,309

PRESENT WORTH = **$** 51,445

Figure E-2. Sample 2.

M & R ALTERNATIVE #3 Overlay the Entire Apron with 7" PCC (Rigid bond)

ANALYSIS PERIOD 20 **YEARS** **INTEREST RATE** 8 **%**

INFLATION RATE 6 **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1978	Slab Replacement with 19" PCC			
	(98 Slabs) @ $1900/Slab	186,200	1.0	186,200
1978	Crack Seal ≈ 184 Slabs			
	(184 x 15') @ $0.35/Ft	966	1.0	966
1978	Apply Bonding Agent @			
	$0.50/SY (≈ 40250 SY)	20,125	1.0	20,125
1978	Place 7" PCC Overlay (Bond)			
	@ $80/CY (23500 SY)	365,555	1.0	365,555
1978	Feathering the Overlay on Each			
	Side (≈ 60 x 2000') @ $80/CY	103,704	1.0	103,704
1978	Joint Seal @ $0.20/Ft	6,405	1.0	6,405
1985	Joint Seal @ $0.31/Ft	10,000	.877	8,770
1988	Joint Seal @ $0.31/Ft (≈10,000 Ft)	3,100	.830	2,573
1988	Localized Repair @ $0.20/SY	4,700	.830	3,901
1992	Joint Seal @ $0.31/Ft (≈10,000 Ft)	10,000	.770	7,700
1993	Localized Repair @ $0.30/SY	7,050	.755	5,323
			TOTAL	$ 711,222

SALVAGE VALUE = 954,333 x 0.688 = **$** 656,581

PRESENT WORTH = $ 54,641

Figure E-3. Sample 3.

M & R ALTERNATIVE #4 Overlay the Entire Apron with 10" PCC (Partial Bond)

ANALYSIS PERIOD 20 **YEARS** **INTEREST RATE** 8 **%**

INFLATION RATE 6 **%**

YEAR	M&R WORK DESCRIPTION	COST $	f	PRESENT WORTH $
1978	Slab Replacement with 19" PCC			
	(67 Slabs) @ $1900/Slab	127,300	1.0	127,300
1978	Crack Seal ≈ 184 Slabs			
	(184 x 15') @ $0.35/Ft	966	1.0	966
1978	Place 10" PCC Overlay (Partial			
	Bond) @ $80/CY (23500 SY)	522,222	1.0	522,222
1978	Feathering the Overlay on Each			
	Slide (≈ 75 x 2000') @ $80/CY	185,185	1.0	185,185
1978	Joint Seal @ $0.20/Ft	6,405	1.0	6,405
1985	Joint Seal @ $0.31/Ft (≈ 10,000 ft)	10,000	.877	8,770
1988	Joint Seal @ $0.31/Ft (≈ 10,000 ft)	3,100	.830	2,573
1988	Localized Repair @ $0.20/SY	4,700	.830	3,901
1992	Joint Seal @ $0.31/Ft (≈ 10,000 ft)	10,000	.770	7,700
1993	Localized Repair @ $0.30/SY	7,050	.755	5,323
			TOTAL	$870,345

SALVAGE VALUE = 962,333 x 0.688 = **$** 662,085

PRESENT WORTH = **$** 208,260

Figure E-4. Sample 4.

INITIAL DISTRIBUTION

HQ AFSC/DEEE	6
HQ AFRES/DEMM	12
HQ ATC/DEMM	20
HQ SAC/DEMM	20
HQ USAFE/DEMO	30
HQ PACAF/DEEE	16
HQ MAC/DE	25
HQ TAC/DE	35
HQ AFESC/TST	2
HQ AFESC/DEMP	2
HQ AFESC/RDCF	13
CERF	2
DDC/DDA	2
FAA/RD430	5
HQ AAC/DEEE	5
HQ AFLC/DEMG	9
AFIT/Tech Library	1
USAWES	10
HQ AUL/LSE 71-249	1
CERL	26
ANGSC/DEM	8
AFIT/DET	2
USAFA/DFCEM	1
HQ AFESC/RDXX	1

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